THE DEVELOPMENT OF COPPER ALLOY METALLURGY IN THAILAND IN THE PRE-BUDDHIST PERIOD, WITH SPECIAL REFERENCE TO HIGH-TIN BRONZES

By

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ABSTRACT

This thesis contains the results of a project designed to investigate the development of copper alloy metallurgy in Thailand from the earliest times down to the beginning of the historical period. Excavated material was obtained from a number of archaeological sites in Thailand, in particular Non Nok Ta, Ban Don Ta Phet and Ban Na Di. Most of this material is well provenanced and can be dated with reasonable accuracy.

Chemical analysis of 276 artifacts was carried out using Atomic Absorption or Induction Coupled Plasma spectroscopy, with phase analysis being carried out using the electron microprobe. In addition, a large proportion of the objects (127) was sectioned and examined using the techniques of optical metallography. From the information that was obtained, it has been possible to build up a picture of the technology of different classes of artifacts, the particular alloy used for each, and regional and chronological variations.

In addition, a considerable amount has been learned of the class of alloy known as β-tin bronzes, which appear to have been used first in Thailand and to a limited extent in other Asian countries up to the medieval period. Information of fundamental interest regarding these alloys was obtained.

TO MY PARENTS AND OUR FAMILY

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1. INTRODUCTION

Earlier work on a group of copper alloy artifacts from Thailand (Rajpitak, 1979) revealed metallurgy of a sophistication not previously known in South East Asia in the prehistoric period. Further and more systematic work seemed desirable, and the present thesis is based on material from excavations carried out by the Thai Fine Arts Department and archaeologists from outside Thailand who have made their material available for study (see acknowledgements).

This thesis is an attempt to investigate the development of copper alloy technology in Thailand, to correlate artifact types with composition, to examine possible correlations between alloy type and chronology, and finally, if it is possible, to look for minor compositional differences which might indicate local variations based upon ore type or provenance. The materials studied are mostly from archaeological excavations in Thailand, although there are some from surveys without full site details and some from private donations to museums.

Work on Prehistoric Archaeology in Thailand is the subject of controversy, especially as to chronology. Insufficient excavations have been done even to fully understand the sequence of prehistoric and early historic periods. This thesis tries to document the development of metallurgy between prehistoric and proto-historic periods in Thailand.

1.1 GEOGRAPHY OF THAILAND

Thailand is a small country situated in South East Asia. The area is 518,000 sq.km. with a population of 48,399,993. Thailand extends from latitude 5°30'N to 21°N, and from longitude 99°E to 106°E. Laos and Burma lie at the northern border, Malaysia at the southern border, Laos and the Khmer Republic (formerly known as Cambodia) at the eastern border, and Burma at the western border (Fig.1).

1.2 EARLY PREHISTORY

The earliest culture of Thailand is Palaeolithic. Although no human remains from this early period are known, some stone tools have been found. It was suggested that these tools (chopping tools) are Middle Pleistocene or even much earlier in the Lower Pleistocene. Van Heekeren (1967) linked the stone tools found at Bo Ploi in Kanchanaburi province with the Patjitanian in Indonesia, dated to the late Middle Pleistocene. In general, the earliest tools can be roughly dated to at least 500,000 years before the present (Butzer, 1965).

In South East Asia the Hoabinhian tool types took over from the chopping tool tradition. The excavations at Sai-Yok (in Kanchanaburi Province) in 1960-1962 revealed 3 main strata - a pre-ceramic pebble-tool horizon, a Neolithic horizon and a historical horizon.

The pebble tool tradition at Sai-Yok was given the tentative date of 8000 to 10,000 years B.C. by Van Heekeren (Heekeren and Knuth, 1967, 1, 63). He gave this date basing

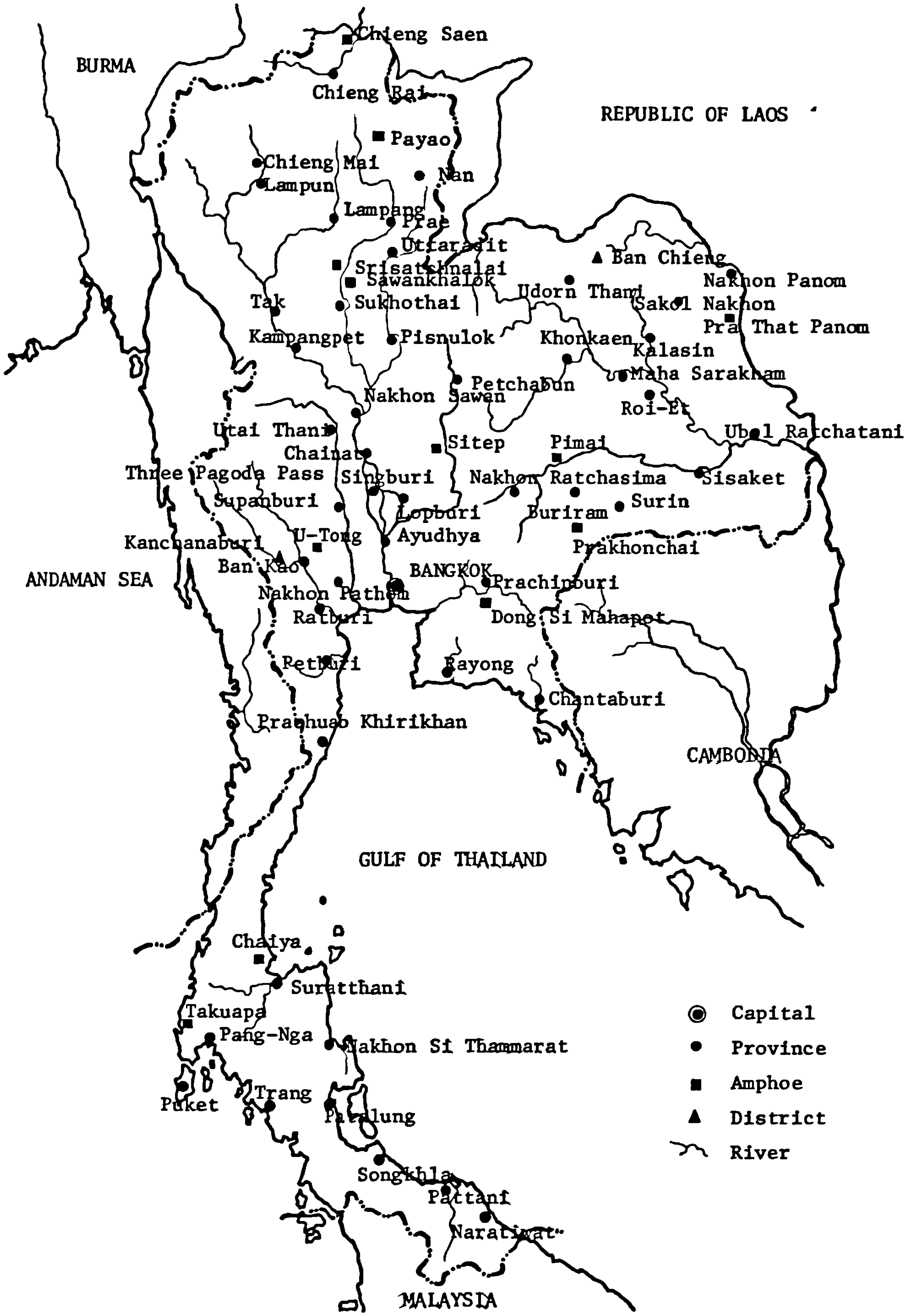

BURMA
REPUBLIC OF LAOS
Chieng Saen
Chieng Rai
Payao
Chieng Mai
Lampun
Nan
Lampang
Prae
Uttaradit
Srisatchnalai
Sawankhalok
Sukhothai
Tak
Kampangpet
Pisnulok
Ban Chieng
Nakhon Panom
Udorn Thani
Sakol Nakhon
Pra That Panom
Khonkaen
Kalasin
Maha Sarakham
Petchabun
Nakhon Sawan
Roi-Et
Utai Thani
Ubol Ratchatani
Chainat
Sitep
Pimai
Three Pagoda Pass
Singburi
Nakhon Ratchasima
Sisaket
Supanburi
Surin
Lopburi
Buriram
Kanchanaburi
U-Tong
Ayudhya
Prakhonchai
Ban Kao
BANGKOK
Prachinburi
ANDAMAN SEA
Nakhon Pathom
Ratburi
Dong Si Mahapot
Petburi
Rayong
Chantaburi
Prachuab Khirikhan
CAMBODIA
GULF OF THAILAND
Chaiya
Suratthani
Takuapa
Pang-Nga
Nakhon Si Thammarat
Puket
Trang
Patalung
Songkhla
Pattani
Naratiwat
MALAYSIA
Capital
Province
Amphoe
District
River

Fig. 1

his hypothesis on animal remains and on the tool types, which in general he identified as Hoabinhian.

1.2.1 The Spirit Cave

The Spirit Cave is a limestone rock shelter some 60km north of the town of Mae Hong Son. It is located in a steep cliff which rises to a height of 600m above the river Salween. The excavation was conducted by Chester Gorman over an area of 25 sq. metres.

The Spirit Cave contained five levels. There are signs of human occupation, stone tools, animal bones, plant remains, potsherds and a hearth. The stone tools are in the Hoabinhian tradition. The pottery is dated to around 7000 B.C. (T.L.) (Solheim, 1972).

1.2.2 The Bayon Cave

Chester Gorman, with the help of Vidhya Intakosai, also excavated the Bayon Cave, in the same district and province as the Spirit Cave. He found a number of Hoabinhian tools and also fifty carbonised rice grains. The discovery of bamboo charcoal in the Bayon Cave has made it possible to obtain radiocarbon dates. The results are as follows:

Level 4: 9180±360 B.P. This level contained remains of almonds, local wild nuts, betel nuts, benas, bottle gourds and water chestnuts.

Level 2A: 8759±200 B.P.

Level 2: 8550±200 B.P. This level contained a hearth in which stone adzes and plant remains (black pepper, betel nuts and local wild nuts) were found.

Level 1: approximately 8000 B.P.

From this evidence, the archaeologists believe that agriculture began in mainland South East Asia around the 7th millenium B.C., at the same period as in the Near East. Some suggest that the people of South East Asia may have been the world's first farmers, since the climate there is much more suitable for the beginnings of cultivation than in other parts of the world.

The Hoabinhian culture found at the Bayon cave falls within the range of the Pleistocene. At Gua Kechil in Malaysia the Hoabinhian sequence is reported to end about 2850±800 B.C. This means that the time-span for the Hoabinhian sequence covers a period of some 8000 years (Gorman, 1971).

1.3 LATER PREHISTORY

1.3.1 Ban Kao

This site is the one which has been most intensively investigated. The site, located on the river Kwae Noi in Kanchanaburi, was excavated in 1960-62 as a joint Thai-Danish effort. It is dated to the Neolithic by its material, which includes stone adzes and pottery.

Sørensen (Sørensen and Hatting, 1967) reported only two instances of iron adzes associated with burials (12 and 23), and ignored other examples found outside the graves during the excavation. The material found also included a few fragments of bronze from the upper levels.

The site must be treated for the time being as an early agricultural one with some intrusive Iron Age burials. The radiocarbon dates (1770±140 B.C., 1360±140 B.C., etc.) suggest that the Ban Kao settlement began around 2000 B.C., possibly with domesticated pigs, chickens and cattle.

1.3.2 Kok Charoen (Lopburi Province)

The objects found include a few stone adzes scattered here and there, not one of them in association with a burial. Pottery was found associated with burials. No metal object or any trace of metal was discovered on the site, and this led Watson and Loofs to argue for a Neolithic date for the material. This site was dated by the thermoluminescence method, one sample giving 1180±300 B.C. and the other 1080±300 B.C. (Watson and Loofs,1967, 1970).

1.3.3 The Lopburi Artillery Centre Site

The objects recovered are of bronze and iron in addition to the stone material typical of earlier periods. The thermoluminescence dates for this site were 700±166 B.C. and 1224±300 B.C. Some pottery types from this site are the same as those from Ban Kao. The site is rich in bronze objects such as earrings, rings, bangles and even socketed axes or adzes. Weapons found included iron spear-heads and axes. Most of the total of 36 burials found in two seasons (1964 and 1965) were fully equipped with personal ornaments, in addition to food and other offerings. Rings and bangles were common types of ornament. (The excavation also yielded material of a later period, probably of the 7th century A.D.)

1.3.4 Ban Chiang

The discovery of artifacts from Ban Chiang and Non Nok Tha, especially bronze objects, has changed opinions of the origins of bronze metallurgy in South East Asia. It has been accepted for a long time that the origin of bronze metallurgy lies in the Middle East, and all developments in other areas have been influenced from this centre.

The discovery of the site of Anyang in the northern part of Honan province, China, first revealed the bronze metallurgy of the Shang Dynasty (c.1600-1027 B.C.). It was assumed by archaeologists working on the material that bronze metallurgy could not have been brought in from elsewhere. The bronze from Anyang was no earlier than c.1300 B.C., whereas in Mesopotamia it was in use as early as c.3000 B.C. The special nature of Chinese bronze metallurgy seems to derive from the art of the potter, but using a unique technique of piece-mould casting. These bronzes from Anyang were of a sophisticated style that must have taken much time to develop, and the techniques were different from those of the Middle East.

Between 1928 and 1937 the Academia Sinica excavated at Anyang. It was accepted at that time and for years thereafter that Anyang bronzes were the earliest evidence for copper or bronze metallurgy from East or South East Asia.

The excavation of the important sites at Erh-li-t'ou in west-central Honan Province, which may have been the capital city of the founder of the Shang Dynasty, and at Cheng-chou, south of Anyang, has produced bronzes that are both earlier and cruder than those from Anyang. It was reported that the radiocarbon date for copper metallurgy at these sites was around 2000 B.C. (Muhly, 1976).

In Thailand, at Ban Chiang (a small village in North-east Thailand), archaeological excavations recovered numerous materials such as pottery, stone and metal artifacts. The proposed dates for Ban Chiang are the subject of disagreement. At this stage, this thesis will use the dates from the papers published by Muhly, etc. (Gorman and Charoenwongsa, 1976).

Phase I and II yielded black to grey burnished and incised pottery. A cast bronze spearhead, bronze anklets and bracelets were found associated with the burials from these phases. The dates published suggested that these phases could be as old as 3600-2900 B.C. It was even older than the earliest bronze metallurgy in China (2000 B.C.), as mentioned earlier.

1.4 SIGNIFICANCE OF DATING EVIDENCE

It is not appropriate in the context of the present thesis to discuss in full the background to the chronology which has from time to time been proposed for the various sites. Nevertheless, it will become apparent that there are severe inconsistencies between different sites, and differences of opinion between the archaeologists involved. The very early dates proposed for metallurgy at Ban Chiang are a case in point.

One aspect of the problem is the small number of absolute dates which are available, but this is made more serious by increasing evidence that the thermoluminescence dates for Ban Chiang and other sites are largely unreliable; indeed many have now been withdrawn. Such dates as have been utilised here are radiocarbon dates from apparently secure contexts, but as yet it is not possible to build up a satisfactory chronology for metallurgy in Thailand.

It does however seem probable that copper alloy metallurgy became established by the first half of the second millenium B.C., and iron was probably not introduced before 500 B.C.

1.5 SITES CHOSEN FOR STUDY

1.5.1 Kok Khon

This site is located at latitude 17°38'18"N and longitude 103°26'11"E (Fig.2) in Changwat (province) Sakon Narkorn. It is approximately 40 km. by road north-east of the site of Ban Chiang. The director of this excavation was Mr. Pisit Charoenwongsa, but no details of this site have been published. It is a burial-habitation type site.

Apart from bronze artifacts, iron tools and silver ornaments were found. The date of this site has not been determined. Charoenwongsa's estimate of the date of this site by comparison of artifact types corresponds to the Late Phase of the Ban Chiang sequence, namely the Iron Age Phase.

1.5.2 Non Chai

Non Chai ("Victory Mound") is a mound site about 1 km.

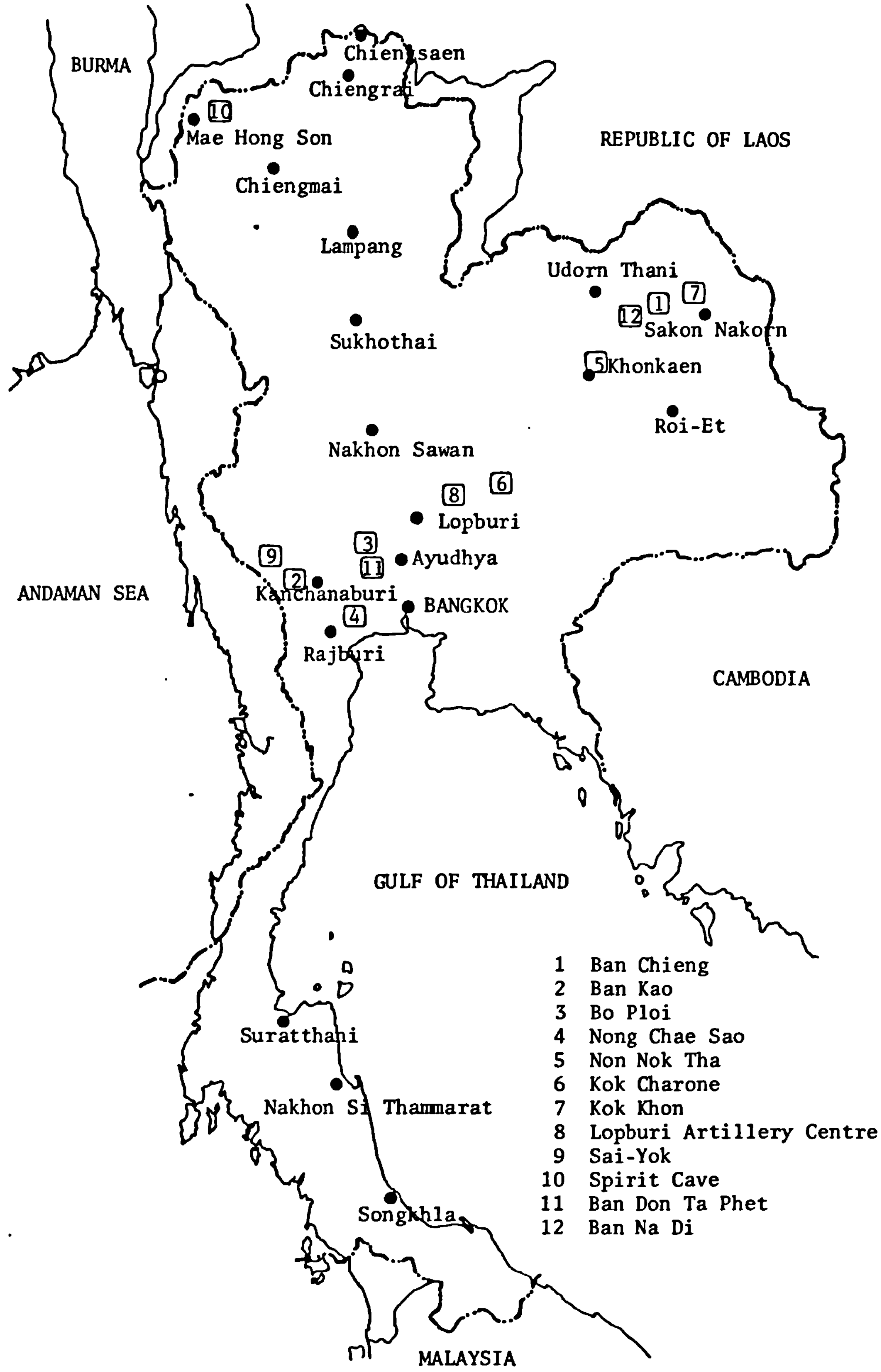


Fig. 2 PREHISTORIC SITES

in diameter rising some 13 m. above the level of the surrounding ricefields.

It is located at latitude $16^{o}27'40''$N and longitude $102^{o}61'40''$E. It is at the northeast end of Amphoe Miiang, Changwat (Province) Khon Kaen, about 3 km. from the Provincial Central Building (Sala Klang Changwat).

Pisit Charoenwongsa,from the Thai Fine Arts Department, conducted a survey of the area in June 1977. The excavations started in June 1977 and ran until September 1978. Four 4x4 m. squares were laid out (designated D1 to D4) and excavated with 1 m. baulks left between all squares. The deepest deposit extended 5.5 m. below the surface.

Stratigraphy:

42 artificial levels were discerned during the excavation. These artificial levels can be classified into 6 cultural layers using as criteria soil texture, colour (based on organic matter in the soil), and the quantity of artifacts present. These six cultural layers may be described briefly as follows:

Cultural layer 1 (from surface down to and including level 2, average thickness 40 cm.). This layer consists of humus and is heavily root-penetrated. The soil is grey. Very few artifacts were found in this layer.

Cultural layer 2 (levels 3 to 13 inclusive, average thickness 120 cm.). This layer is more porous in texture. The soil is brownish grey. A larger number of artifacts were recovered from this layer.

Cultural layer 3 (levels 14 to 24 inclusive, average thickness 105 cm.). More artifacts were recovered in this layer than in layer 2.

Cultural layer 4 (levels 25 to 33 inclusive, average thickness 110 cm.). More sherds were recovered from this layer than other layers.

Cultural layer 5 (levels 34 to 39 inclusive, average thickness 75 cm.). Smaller amounts of artifacts were recovered than from layers 3 and 4.

Cultural layer 6 (levels 40 and 41, average thickness 50 cm.). This layer is free from pottery but did contain a small number of animal bones.

Types of artifact:

Large amounts of sherds, human bones, iron fragments, bronze artifacts, glass beads, clay mould fragments for the lost wax casting of bronze bells, and sandstone moulds for piece-mould cast bronze axes were found.

The total number of iron fragments was 148. A broken iron object, possibly a socketed axe, was recovered from level 11 of square D3.

The total number of bronze fragments was 123. These bronze artifacts were mainly fragments of ornament, e.g. bracelets, rings and bells. Numbers of blue glass beads were also found. Clay moulds for the lost wax casting of bronze bells were recovered from level 23 in square D3, and sandstone moulds for the casting of bronze axes were found in levels 15, 16, 20 and 22.

A few fairly complete pots were recovered. Other artifacts found included 2 shouldered adzes and a few clay artifacts, semi-lunar in shape, which are of unknown function.

Reported date

Two radiocarbon dates supplied by the Thai National Energy Department are as follows: 1520±234 B.P. from square D1, level 38; and 1760±24 B.P. from square D3, level 12. Corrected to a half-life of 5730 years, these dates are 1566 B.P. and 1813 B.P. respectively.

The proposed date for the site is between 0-500 A.D. (Somsuda Rutnin, 1979), i.e. protohistoric iron-age.

1.5.3 Kok Ma Kamtao

This site is situated at Tambon Donka, Amphoe Banpae (บ้านแพ) Changwat Ratchaburi. It is located at latitude 13°39'41"N and longitude 100°03'20"E. The site yielded animal bones, human bone, ornaments (e.g. glass beads), bronze bracelets, stone bracelets (chlorite schist) and pottery. There is no reproted date for this site. This site has not been excavated by any archaeologist. It was surveyed by Son Dangyed from the Archaeological Division, Thai Fine Art Department (Sod Dangyed, 1978).

1.5.4 Noen Klong Bamrung

This site is situated in Amphoe Chai Badan, Tambon Nong Yai Toa, Changwat Lopburi. Miss Sangchan Trikasem from Bangkok National Museum was the excavator. The report of this site has not yet been published. There are burials with a very few bronze lumps. The most interesting artifacts are moulds and crucibles. From the quantity of these metal working tools it is possible that this site contains a metal worker's burial. Curiously enough, there are hardly any other artifacts found in this site.

1.5.5 Non Nok Tha

Non Nok Tha ("Partridge Mound") is a low mound lying some 500 m. south of the village of Ban Na Di in north-western Phu Wiang district in the western end of Khon Kaen Province. It is located some 2.5 km. north of the foot of the large, low sandstone mountain after which the district is named. The mound itself is located at latitude $16^{o}47'57"$N and longitude $102^{o}18'17"$E.

This site was first located by Chester F. Gorman during the first season of the programme in April 1964, while surveying the western end of the proposed Nam Pong Reservoir (Solheim, 1966, 13-15; Solheim and Gorman, 1966, 164-179). At this time the site was designated Nam Pong 7. Extensive test excavations were conducted by Ernestine Green in January 1965 (Solheim, Parker and Bayard, 1966, 77-81). It was found that this site was one of probable importance. In 1966 Hamilton Parker, Donn Bayard and Wilhelm G. Solheim II excavated a portion of the site, establishing for the first time in Southeast Asia an extended period of bronze working and use without the presence of iron. The site was then referred to as Ban Nadi (Solheim, Parker and Bayard, 1966; Solheim, 1966, 40-41). The area of the 1966 excavation was 150m^2.

The 1968 excavation at Non Nok Tha represents the fourth year of archaeological interest in the site and the second season of intensive area excavation. The director of this excavation was D.T. Bayard. The area of the 1968 excavation was $190m^2$.

This site proved to be the first to provide definite evidence of a distinct bronze period in South East Asia (Bayard, 1980, 171) and is also one of the largest areas of excavation carried out there to date.

The $340m^2$ excavated at Non Nok Tha provided a large number of bronze artifacts: 72 artifacts and artifact fragments were recovered (Table 1). Substantially complete artifacts include 5 axes, 27 bracelets, 3 small beads, and a socketed arrowhead. There were also 10 whole and 13 fragmentary bivalve mould halves, all made of local sandstone. Four whole ceramic crucibles and 12 crucible fragments provide further evidence for local manufacture. There were 496 bronze nodules of which the majority are clearly spillage from casting (Smith 1973,30; Selimkhanov 1979,33).

Table 1
(Bayard, 1981)
Non Nok Tha Bronze

	1966 ($150m^2$)		1968 ($190m^2$)	
	Nodules	Artifacts or Fragments	Nodules	Artifacts or Fragments
Late Period	118	13	92	8
Middle Period	84	32	165	16
Early Period	4	0	4	1
Provenance doubtful	26	1	3	1
TOTAL	232	46	264	26

Reported dates:

The chronology of this site has been a subject of controversy. The problems have been discussed by Bayard in many articles. Bayard feels that the balance of evidence at present still supports a date of about 2500 b.c. (c.3200 B.C. calibrated) for the Early Period/Middle Period transition and by implication, a date some 500 years earlier for the still inadequately dated basal levels of the site.

(Solheim, Parker and Bayard, 1966; Solheim, 1966; Solheim, 1967a; Solheim 1967b; Solheim, 1968a; Solheim, 1968b; Solheim, 1969; Solheim, 1970; Bayard, 1970; Bayard, 1971; Bayard, 1972; Bayard, 1975; Bayard, 1979; Bayard, 1980a; Bayard, 1980b; Bayard 1981; Pittioni, 1970; Smith, 1973; Wheeler and Maddin, 1976; Selimkhanov, 1979)

1.5.6 Ban Na Di

Ban Na Di is situated in Tambon Phang-ngu, Amphoe Nong Han, Changwat Udon Thani, Northeastern Thailand. It is located at latitude 17°15'12"N and longitude 103°06'43"E. It is a low mound 120 m. wide and 150 m. long.

This site was surveyed by Charles Higham and Amphan Kijngam. The principal objectives were to map and assess the settlement pattern of the Ban Chiang culture, and to locate an undisturbed site for excavation. Ban Na Di provided a 4½m. deep cultural sequence incorporating both occupational and burial material, and is situated about 25 km. southwest of Ban Chiang. The excavation of one 4x4 m. and four 3x3 m. squares was conducted from November 1980 to May 1981. The site yielded 59 inhumation burials with associated grave goods. The excavation also revealed the occupation levels and industrial activity.

Higham (1981) reported that in terms of burial and utilitarian ceramics, the site was occupied during the equivalent of Ban Chiang phases III to VII. There were also complete vessels not paralleled in the Ban Chiang assemblage.

Bronze was present and locally cast throughout the site's use. Bivalve mould fragments, pieces described as partially smelted ore, bronze casting furnaces, crucibles, bronze arrowheads, bangles, and chisels were found. All the furnaces yielded *in situ* charcoal samples. Iron appeared during the occupation level equivalent to Ban Chiang phase IV.

There are also numerous *in situ* hearths, and pits sealed at the neck by a thick layer of charcoal. Such samples provide *termini ante* or *post quem* for the burials. Higham contended that it is the first time provenanced samples of charcoal were available to date the phases of the Ban Chiang culture.

Proposed dates:

Range from 1940 B.C. - 100 A.D.

600 B.C. - 100 A.D.: Iron in use

1500 B.C. - 600 A.D.: Bronze in use

(Higham, 1981; Higham and Kijngam, 1982; Bayard, 1982)

1.5.7 Ban Don Ta Phet

Ban Don Ta Phet is a village which is situated in Amphoe Phanom Thuan, Changwat Kanchanaburi. The site is a cemetery on the edge of the village, which is 8 km. north of Amphoe

Phanom Thuan and a little to the west of the road between Kanchanaburi and U-Thong in west-central Thailand. The part of the site excavated is in the grounds of the Salvanaram School.

On September 25, 1975, while digging post holes for a fence at the Salvanaram School, a lot of objects were found at a depth of 50-60cm.

There have been two seasons of excavations so far. The first excavations were conducted by Mr. Nikom Suthivak (November 1975) and later on by Mr. Chin You-di (1976). Fourteen squares of 4x4 m. and two test pits were excavated. The finds occur at a general depth of 60-129cm.

The site was published in a preliminary report by Mr. Chin You-di (1976) at the time of an exhibition of the finds from the site held at the Bangkok National Museum. Mr. Chin You-di described the site as an Iron Age secondary burial area. There is no evidence for settlement in the area excavated.

The burials consisted of whole skeletons or parts of skeletons (e.g. arm bones or jaws and teeth) accompanied by groups of objects. The finds included a large number of sherds of pottery, glass, stone tools, iron (about 579 pieces), copper alloy artifacts (about 163 pieces) and 2226 beads of various materials (Pl.1,2,3,4). Some of the metal objects and pottery were apparently deliberately broken or damaged before burial.

The copper alloy artifacts are of particular interest. These are containers such as bowls, personal ornaments such as bracelets, anklets, and rings, three finials in the shape of birds (Pl.5,6,7) and other objects such as ladles and small spherical bells. Some of the objects were decorated; most of them are exceptionally thin and were probably cast by the lost wax method. There is no evidence of metal working on the site.

The bronze artifacts from the first excavation at this site were studied by the author and reported in detail (Rajpitak, 1979). A paper has also been published concerning the unusual high-tin bronze artifacts from Ban Don Ta Phet which indicate a sophisticated metallurgical tradition (Rajpitak and Seeley, 1979). In the present work more detailed studies of the unusual structure of the high-tin bronze artifacts are reported. The objects studied are from the first and second excavations at Ban Don Ta Phet. The second excavation (November 1980-January 1981) was directed by Dr. I.C. Glover of the Institute of Archaeology, University of London, and Mr. Pisit Charoenwongsa from the Archaeological Division of the Thai Fine Arts Department. This second excavation again provided evidence that the site was a burial site. Several main categories of grave goods were found: pottery vessels, pottery spindle whorls, bronze containers, bronze armlets and anklets, glass beads and bracelets, stone beads and iron tools and weapons. Among these artifacts, four unique pieces were found: a carved carnelian "lion" pendant, a bronze bucket, a cast bronze cockerel (Pl.8, top part) and a bronze cage possibly belonging to the cockerel (Pl.8, lower part) (Glover, 1981).

Date of the site

The radiocarbon date from the British Museum Research Laboratory was given as 1810±210 B.P. (R. Burleigh, personal communication). The date corresponds to the date estimated by Mr. Chin You-di from the comparative material. He proposed that this site belongs to the Iron Age of Thailand (about 1700-2000 years B.P.). There is other evidence (Sørensen, 1973) that this period in Thailand may begin as early as 300 B.C., and indeed Sørensen reports a bronze vessel possibly related to those from Ban Don Ta Phet from his Tam Ongbah site.

Some of the beads found at Ban Don Ta Phet are particularly interesting and may be used as dating evidence. The etched carnelian and agate beads are very similar to examples found in India in a context datable to 300-200 B.C. (Beck, 1944; Beck, 1941; Dikshit, 1949). The beads at Ban Don Ta Phet were probably imported from India because such beads are not known to have been manufactured in South East Asia (Lamb, 1965; You-di, 1978; Glover, 1981; Rajpitak and Seeley, 1979).

1.6 PREVIOUS WORK ON METALLURGY IN THAILAND

Cyril Stanley Smith studied some artifacts from Non Nok Tha (Smith, 1973), consisting of a bronze axe, two bracelets, bronze nodules and clay crucibles, and also a wire ring fragment from Pimai.

Qualitative spectrochemical analyses have been carried out on these objects by Richard Pittioni of Vienna (Pittioni, 1970). The report shows that they all contain copper as the principal component, with tin and lead in minor amounts, and a trace of silver. It can be said that they were all normal leaded bronzes. Smith's metallographic investigations yielded the following evidence: The microstructure of the bronze axe suggests that it has been cast in a two-piece (bivalve) mould with a core to shape the socket hole. A two-piece sandstone mould is illustrated in Fig. IIIa of Sølheim's report (Sølheim II, 1968). The bracelets are cast. The nodules are drops of metal spilled from a crucible or running out of a mould and solidifying on an earthen floor. They are not formed into shape by a mould or other surface. The structure is the typical distorted structure of a cast bronze. The crucible is similar to the crucibles that are found in early metalworking sites in both the Middle East and in Europe. The wire ring fragments from Pimai have the structure of a bronze containing about 20 percent tin. The structure is α-phase in β-martensite. This structure is identical with the microstructure of the Korean bronze published by Voce (Voce, 1951).

Maddin and Wheeler (1976) examined 19 bronze artifacts from Ban Chiang and 9 objects from Non Nok Tha. The objects studied from both sites included spearheads, bracelets, a necklace, a ring, an anklet, a piece of bar stock and several unidentified fragments.

Since most of the objects studied were heavily corroded, accurate elemental analysis was difficult. Elemental analysis was performed by x-ray fluorescence and wet chemical methods. Most of the specimens studied are made of normal tin bronze containing about 10% tin with some impurities.

A spearhead dated to about 3600 B.C., which was claimed to be the earliest known metal object from Ban Chiang, was analysed by optical emission spectroscopy. The tin content is 1.3%. Eight of the 25 specimens contained lead in concentrations of 1-5.5%. It was suggested that lead had been added deliberately. Another suggested possibility was that lead ore occurred in the area of the copper source close to Ban Chiang and lead may be an unintentional component of the alloy.

A necklace from Ban Chiang, which probably dates from the period 0-500 B.C., is the most interesting piece in the collection. The metallographic structure revealed α-phase in acicular β-martensite. The proportion of tin in the object was around 22-25 wt % tin. The microstructure of the Ban Chiang necklace corresponds closely to that of the Pimai rings and the Korean bowl of the 12th-14th centuries A.D. studied by Voce. This high-tin alloy was also used for Sassanian bowls and is best known in the West as cymbal metal.

Two decorated bracelets from Non Nok Tha were examined to determine how the decoration was formed or applied. It was proved that they were cast in one piece by lost wax casting, rather than the decoration being applied by welding or some other type of joining.

A bimetallic artifact, a spearhead with iron blade and bronze socket, was found in phase IV of Ban Chiang (1600-1300 B.C.). The optical micrograph shows a cast and unworked bronze structure. The iron blade was made first and the bronze socket cast onto it.

Carriveau (1974) proposed another method of obtaining a reliable date by seeking evidence that was directly related to the metalworking activity. This might be obtained from hearths, furnaces, metalworking tools, metals, or slag.

In the past, nearly all smelting or metal production dating has relied on thermoluminescent dating or radiocarbon dating of associated materials such as pottery or charcoal. One must be sure that these artifacts are contemporaneous with the activity studied.

Two fragments of a crucible from Non Nok Tha (Carriveau, 1974, fig.1,2, p.60) were studied. The T.L. date arrived at for the crucible was 1120±520 B.C. A corrected radiocarbon date for an associated level was 890±100 B.C. (private communication between Carriveau and Sølheim). The corroded metal droplets were removed from the crucible fragments and the droplets analysed by scanning electron microscopy with an energy dispersive, solid-state detector.

The result of the analysis showed that the Non Nok Tha bronze samples had more than 10% tin with a low concentration of lead.

Another date has been obtained for reconstructed crucibles from Ban Chiang (Carriveau, 1974, fig.6,7, p.61). Thermoluminescence dates from these crucibles are in the second millennium B.C. and compare well with radiocarbon dates from adjoining levels. The analysis of the material remaining on the crucible indicates a high-tin (>10%), low-lead bronze.

A cast bronze axehead with its sandstone mould (Carriveau, 1974, fig.10, p.64) was also studied. The thermoluminescence date of the mould has not been obtained yet. Metallographic analysis of the cast bronze axehead shows that the outside surface of the metal cooled very slowly, suggesting that the mould was preheated, possibly to reduce cracking of the mould when the molten metal was poured in, and to avoid flaws resulting from rapid chilling of the metal.

Pottery sherds and slag from Pimai have also been dated by the T.L. technique. One piece of slag and three sherds were from exactly corresponding levels. The results show that there is an excellent correlation between the slag and pottery dates from the same level (Table 2).

Table 2

Dating Material from Pimai, Thailand

(Carriveau, 1974)

dates	Level 6	Level 6b	Level 7 M7	Level 7 M8	Inexact Level
Sherds	150± 530BC	510±370BC	108±312BC	-	1040±370BC
Slag	1859±1380BC	949±585BC	-	1323±824BC	870±420BC

These dates indicate an iron metallurgy activity at Pimai in the first millennium B.C. There are no radio-carbon samples from this site.

Selimkhanov (1974) has carried out spectroanalytical investigations of 27 metal finds from the mound of Non Nok Tha. These metal pieces were incomplete objects and lumps of metal spilled during casting. All of these samples were so corroded that there was no remaining metallic core. The results obtained can be summarised as follows:

1. All of the samples are tin bronze (more than 8 wt % tin). They can be grouped into categories:

a. tin bronzes with a very small amount of other metals;

b. tin bronzes with a high proportion of iron with other metals as traces.

2. There is no pattern in the tin content of samples found in different levels. The oldest bronze samples, dated to 2700 B.C., are reported to contain 14.2%; and those dated 200 A.D. contain 19.1% and 11.1% of tin.

3. All bronzes from Non Nok Tha are of simple composition, mostly copper alloyed with tin, except in 3 samples when iron is also present (3.1%). Other metals are present in very small amounts.

4. Among bronzes from Non Nok Tha investigated by Pittioni, there are tin bronzes containing lead (Pittioni, 1969), but in bronzes investigated by Selimkhanov, lead is present only in trace amounts.

2. EXPERIMENTAL

The two main lines of investigation of the copper-tin alloy artifacts from Thailand were their chemical composition and technology. For chemical composition, various techniques for elemental analysis were carried out. Atomic absorption and induction coupled plasma analysis were the two main techniques used in chemical analysis, although X-ray fluorescence spectroscopy was also used for a small number of objects. For the study of the technology of the artifacts, visual examination, X-radiography, and optical metallography were used. In addition, for phase identification, the technique of electron probe microanalysis was carried out.

2.1 VISUAL EXAMINATION

The artifacts were photographed and examined by the naked eye and binocular microscope. Evidence of working, such as hammer marks and polishing marks could be seen clearly on the surface of some of the artifacts. For non-corroded artifacts, the decorative detail could be seen very clearly on the surface.

2.2 X-RAY RADIOGRAPHY

The Faxitron (Field Emission Corp.) X-ray machine was used for X-radiography. A number of objects were examined by X-radiography to reveal details of internal structure or surface detail concealed by corrosion products. From the X-radiograph one could also identify sound areas of metal which could be sampled for chemical analysis and optical metallography. A wide range of X-ray tube voltages and exposure times was used, depending on the thickness of the objects. The film used in taking the X-radiographs was Kodak Industrex X-ray film.

2.3 SAMPLING TECHNIQUE FOR ELEMENTAL CHEMICAL ANALYSIS

Many of the artifacts of bronze were rather difficult to sample, as the alloy is hard. The most suitable way to take the sample was found to be by using a precision printed circuit board (P.C.B.) drill. Three types of twist drill bits were used together with this P.C.B. drill: a high speed steel bit of 1mm diameter, a high speed steel bit of 0.6mm diameter for very small objects, and a tungsten carbide P.C.B. drill bit of 1mm diameter for the hardest alloys. Although very hard, this type of bit is also very brittle, and was not economical for general use.

A drill stand was also used together with the drill in sampling many of the artifacts. It was found that the most effective and quickest way to take samples from small artifacts was by using the drill in the vertical position in the drill stand. A sample clamp was essential for small objects. For objects of irregular or difficult shape, it was often necessary to take the sample from the mounted specimens prepared for optical metallography. It was general practice to drill a hole deep into the surface of the artifacts until it reached sound metal. The corrosion products from the first stages of drilling were discarded. The drill bit was changed or cleaned before drilling into the metal of the artifact to avoid contamination. A clean small paintbrush was used in cleaning the drill bit. The artifact itself was wrapped in clean paper exposing only the area to be sampled in order to avoid contamination by loose corrosion products from the surface of the artifact dropping into the sample. The drill bit was usually changed after finishing drilling each artifact. It is prefereable not to use the same drill bit on more than one artifact to avoid contamination. The high speed steel drill bit normally became blunt after one drilling. For the high tin bronze, it was found that a tungsten carbide drill bit gave a better result and could be used for drilling at least two objects. The drill bit was carefully cleaned after finishing drilling each object.

For some artifacts with very thick corrosion products, mechnical cleaning by scalpel, needle and an abrasive were used to remove the corrosion product from the area to be sampled. Then the precision drill was used to take the sample on the same manner as described above.

The samples for analysis were stored in air-tight polyethylene sample tubes and kept in a specimen cabinet containing silica-gel.

2.4 SOLUTION PREPARATION FOR CHEMICAL ANALYSIS

Solutions were prepared by the method described by Hughes, Cowell and Craddock (1976). 5-10mg of sample taken from the artifact was weighed accurately on a Sauter micro-analytical balance. The minimum amount of the sample should ideally not be less than 5mg although this was not always achieved. The sample was then transferred into a 10ml conical flask by pouring through a small glass funnel. One ml of aqua regia (1 vol. conc. nitric acid : 3 vols. conc. hydrochloric acid) was then added to the flask to dissolve the sample. The conical flask with funnel in place was then put on a thermostatic hot plate at 50-60^{o}C to increase the rate of dissolution. Dissolution of the sample on the hot plate was carried out under a fume hood. When the sample was dissolved the flask was removed from the hot plate and left until cool. Another 1ml of aqua regia was added to the flask. The solution was transferred to a 10ml volumetric flask. Distilled water was added until the total volume of the solution was 10ml. The solution was transferred into a polyethylene sample container ready for analysis.

Some samples were not dissolved completely due to the presence of insoluble particles. The solution was decanted into the volumetric flask and made up to 10ml.

These solutions were used for analysis by both atomic absorption and induction coupled plasma analysis. Automatic pipettes with disposable tips were used in measuring the volumes of the acids.

A sample of British Chemical Standards gun metal no. 207/2 was dissolved by the procedure described above. This solution of gun metal was used as a control in each batch of analyses in order to compare the results obtained with its known value. The gun metal was obtained from the Bureau of Analysed Samples Ltd., Middlesbrough, Teeside, England.

2.5 PREPARATION OF STANDARD SOLUTIONS FOR ATOMIC ABSORPTION AND INDUCTION COUPLED PLASMA SPECTROSCOPY

BDH standard solutions for atomic absorption spectroscopy were used in the preparation of the standard solutions. The standard solutions were originally prepared for induction coupled plasma spectroscopy. They were also used in atomic absorption spectrometry.

Standard solutions of the following elements were prepared for the analysis: Cu, Ag, Au, Fe, Co, Ni, As, Sb, Bi, Sn, Zn and Pb. Four standard solutions were prepared for induction coupled plasma spectroscopy. The total volume of each composite standard solution was 250ml. For copper, AnalaR copper foil from B.D.H. was used in the preparation of standard solutions. The copper foil was cut with scissors and weighed accurately.

The copper foil was transferred into a conical flask with a glass funnel on top. 20ml of concentrated nitric acid (AnalaR) were added to the flask to dissolve the copper metal. The flask was then placed on the thermostatic hot plate at 60^{o}C to speed up the dissolution rate of the copper. This copper solution was then transferred to a 250ml volumetric flask.

The standard solutions of Ag, Au, Fe, Co, Ni, As, Sb, Bi, Sn, Zn and Pb were also added to the same flask in the amounts which were calculated. In order to reach the required concentration, distilled water was added in the flask until the total volume of the composite standard solution was 250ml. Automatic pipettes with disposable tips were used in the preparation of the standard solutions.

Another three composite standard solutions of different concentration were also prepared in the same way. The concentration of elements in each standard solution is shown in Table 3.

2.6 ATOMIC ABSORPTION SPECTROSCOPY

The theory of atomic absorption will not be discussed in detail here. There is much literature explaining the subject in depth (Skoog and West, 1971). The application of atomic absorption techniques to archaeology was also published by Hughes, Cowell and Craddock (1976).

In atomic absorption spectrometry, the ultra-violet or visible light with a sharply defined wavelength, which corresponds to the characteristic emission wavelength of the particular element chosen for analysis is focussed onto the atomized sample. Since, for isolated atoms, absorption and emission occur at the same characteristic wavelength, the atoms of the chosen element absorb a proportion of the incident light; the energy associated with the light being transferred to the outer electrons which are consequently excited out of their ground states. The extent to which the light is absorbed therefore provides an estimate of the concentration of the chosen element in the sample. Light of the characteristic wavelength is provided by a hollow cathode lamp; the sample, which is in solution, is atomized in a flame and the intensity of the emergent light beam, after absorption by the sample, is measured using a photomultiplier. A different lamp is required for each characteristic wavelength so that the analysis of each element necessitates a separate measurement (Tite, 1972).

In this project, atomic absorption spectroscopy was the only technique used for the analysis of copper in 65 samples. Other elements were analysed by induction coupled plasma analysis. The results of the analyses of 65 samples for copper by atomic absorption spectroscopy and 276 samples for other elements (Sn, Ag, Au, Fe, Co, Ni, As, Sb, Bi, Zn and Pb) by inductively coupled plasma spectroscopy (ICP) are presented in Table 4.

The atomic absorption spectrophotometer used in the analysis was a Varian Techtron AA-4. The following conditions were used for flame determinations with air/acetylene mixtures. The copper lamp was used at a current of 5mA and a wavelength of 327.5 nm, with the burner rotated by 45^{o}. The detection limit was approximately 1 ppm.

The absorbance of the copper in the four standard solutions was measured. A calibration graph was prepared for individual elements (in this case only copper). The absorbance readings were plotted against the known concentration of copper in parts per million (ppm).

From the absorbance readings of copper in the samples and the calibration curve, the percentage of copper in the sample could be calculated from the following formula:

$$x\% = \frac{c.v.z}{10.w}$$

where: x% = the wt.% of the element in the sample
c = the concentration of element in solution (in ppm)
v = the original volume of solution (in ml)
z = the dilution factor (if any)
w = the weight of the sample in mg.

The sensitivity of atomic absorption is quite high. The typical sample requirement is between 0.2-1.0 mg/ml. For small samples of about 10mg, it is possible to obtain quite accurate results. For the major elements an accuracy of ±1% can be expected. In the case of minor and trace elements, the approximate average error would be ±5% for elements present at concentrations lying between about 0.5 and 0.05 wt% in the material and ±15% for trace elements under 0.05 wt%. For elements present below 0.05 wt% an accuracy of ±5% can be maintained, even down to relatively low concentration, with the use of a flameless atomizer unit.

2.7 INDUCTIVELY COUPLED PLASMA OPTICAL EMISSION SPECTROSCOPY

The principle of inductively coupled plasma (ICP) spectroscopy is similar to the principle of flame emission spectroscopy. Flame emission spectroscopy is a spectral method in which excitation is brought about by spraying a solution of the sample into a hot flame. The flame in the emission spectrometer serves to convert the constituents of the liquid sample into the vapour state and to excite their electrons, which then emit light as they return to the ground state. Inductively coupled plasma is used as an emission source in the inductively coupled plasma optical emission spectrograph.

The atomic absorption technique is more sensitive than flame emission spectroscopy. This difference in sensitivity was predicted from the abundance of atoms in the ground state ready to absorb energy, compared to the relative sparsity of excited atoms ready to emit energy. The development of inductively coupled plasma as the emission source with its higher temperature and excitation capability has resulted in the improvement of emission spectroscopy.

Much research has been devoted to the development of inductively coupled plasma emission spectroscopy.

The main parts of the instrument are the emission source, for which an inductively coupled plasma source is used, the atomizer for spraying the sample into the plasma, and the optical and electronic system for detecting the emission spectra from the samples.

The ICP system was easy to operate. The result of the emission in the form of intensities was recorded and printed out by the computer, giving the intensity of each element present in the sample simultaneously. The machine used for this project was an emission spectrometer, Phillips PV8490ICP, in the Geology Department of King's College, University of London.

The advantage of using a plasma emission spectrometer over an atomic absorption spectrometer is that all the elements in the sample are analysed simultaneously, requiring therefore a much smaller sample (~2ml). The ICP analysis was quicker to perform than atomic absorption analysis, while both techniques give similar accuracy. The technique is very useful in the analysis of very small samples. The details of the advantages of inductively coupled plasma optical emission spectroscopy were described in detail by Greenfield and McGeachin (1980).

276 samples were analysed by inductively coupled plasma emission spectroscopy. Four composite standard solutions (see section 2.5) were run in the beginning and again after every ten samples analysed. Distilled water was run in between each sample. This method of operation can avoid error due to machine drift during analysis over a long period of time.

The result of the analysis of the elements in a sample was printed out in the form of intensities by the computer printer. The calibration graph of the individual elements can be prepared in a similar manner to that for atomic absorption spectroscopy. The intensity readings of each element from the 4 standard solutions were plotted against the known concentration of the element in parts per million (ppm). From the intensity readings of the elements in the samples and the calibration graph, the percentage of the elements in the sample could be calculated from the same formula as for atomic absorption spectroscopy:

$$x \text{ wt\%} = \frac{c.v.z}{10.w}$$

(see details in section 2.6).

The results of the analyses of 276 samples are presented in Table 4. The results of the analyses for the major element, copper, were not completely satisfactory in either analytical technique. For the uncorroded samples, the composition of copper was obtained by subtracting the sum of percentages of other elements from 100%.

2.8 X-RAY FLUORESCENCE

The specimen to be analysed by X-ray fluorescence is irradiated with primary X-rays which displace electrons from the inner orbits of the constituent atoms. The vacant inner electron energy levels are immediately filled by electrons from the outer orbits which are higher in energy. The excess energy will be released in the form of radiation with wavelengths in the range from 2×10^{-5} to 2×10^{-4} μm. Each element emits secondary X-rays at several characteristic and sharply defined wave-lengths. Consequently, the determination of the constituent wavelengths of the secondary X-rays provides the basis for identifying the elements present in the specimen, while the intensity of the X-rays at a particular wave length provides an estimate of the concentration of the associated element.

The primary exciting X-rays are obtained from a high voltage X-ray tube. The characteristic secondary X-rays are separated into their constituent wavelenths using a diffracting crystal and are then detected with a scintillation counter (Tite, 1972).

For corroded specimens, the analytical technique which is the most useful, simple and quick is X-ray fluorescence spectroscopy. The purpose of the analysis is only to identify the major elements of the sample. This technique is also non-destructive. A few corroded samples were analysed by this technique. If the size of the object was not too great it was put in the specimen chamber of the instrument for the analysis. If the samples were too large to be put in the specimen holder, a sample of the corrosion product was scraped off for analysis. The corrosion product was put onto adhesive tape and placed in the specimen holder.

A Siemens wave length dispersive spectrometer was used for the work. The primary X-ray source was a tungsten tube operated at 50 kv, 25 mA, and the analyser was a lithium fluoride crystal cut parallel to the [200] plane. The detector was a scintillation counter and the spectra were directly plotted on a chart recorder. The analyser was rotated through an angle of $\theta = 5^{o}-33.5^{o}$ and all elements above manganese in atomic number could be detected.

Some samples which were prepared for metallography were also used for X-ray fluorescence analysis. The polyester resin block of the mounted sample was trimmed in order to give the right size for fitting in the sample holder of the machine. Twenty-one samples from eighteen objects from Ban Don Ta Phet were analysed (Rajpitak, 1979, Table 1).

For objects from other sites, X-ray fluorescence was used in the qualitative analysis of very corroded objects and objects which could not be sampled for quantitative analysis by other techniques.

2.9 METALLOGRAPHY

2.9.1 Theory

Atoms of metals bond together with a metallic bond. Metal atoms tend to form a crystal structure in which they pack together as closely as possible. This system of arrangement is called a close-packed system. The arrangement of metal atoms is usually regular. The regular repeating units of crystal lattices of a metal are usually hexagonal close-packed (e.g. Mg, Zn, Cd), face-centered cubic close-packed (e.g. Cu, Ag, Au, Al, Pb, γ-Fe), or body centered cubic structure (e.g. Cr, Mo, W, α-Fe).

In a sample that is a single crystal the crystal lattice will have a single orientation throughout the sample. Most metal samples are polycrystalline, however, and are composed of crystals with different lattice orientations. The planes at which crystal lattices of different orientation meet are called grain boundaries. Each zone which has a single-orientation is called a grain. The shape of grains and grain boundaries can be seen under the metallographic microscope. The metal needs to be prepared by a suitable method. The term microstructure means these grain structures. Sometimes the term metallographic structure is used instead of microstructure. The following methods were used for the metallographic examination of the bronze artifacts.

2.9.2 Sectioning of Area to be Examined

The metallographic section must be taken in a suitable place on the object in order to be representative of the whole object. For example, for the containers, the rim and body were cut. If it is not possible to section at more than one place, a section being cut should be representative of the whole object. When it had been decided where the section was to be cut, the method of sectioning was chosen. Several methods were used, such as hand cutting with a jeweller's saw, with a mini-drill with core-drill bit and with a specially designed low-speed saw with a diamond wafering blade (Buehler 11-1180 Isomet low speed saw).

2.9.3 Mounting the Specimens

The metal samples were mounted in a cold-curing polyester resin (Scandiplast 9101) in a standard 25 mm mould. For very small sections which would not stand unsupported in the mould, a special technique was used. The sample section was glued onto a small slip of wood, then it was held in the middle of the mould by clamping the upper part of the small stick.

The mounting process must be completed within 10 minutes, and then left to set for between 2-4 hours.

2.9.4 Grinding and Polishing

Grinding was carried out on waterproof silicon carbide papers of grades 220, 320, 400 and 600, on a Metaserv hand grinder. The specimen was ground in one direction on the coarests grade of paper, then turned by 90° for the next grade of paper, and so on. The grinding was continued until all the previous grinding marks changed to the new direction. The final grinding of the sample was finished on silicon carbide paper grade 600. The specimen must be thoroughly washed under running water or in distilled water in an ultrasonic cleaner in between the grinding of each grade of paper, otherwise the residue from the grinding will cause deep scratches in the sample section. For high-tin bronze it was very difficult to grind the surface of the sample down due to its hardness. For low tin bronzes, grinding was much easier and quicker.

Polishing

The specimen must be washed to remove the abrasive substance or foreign substances before the start of polishing and in between each stage of polishing by washing in distilled water and a few drops of a non-ionic detergent in an ultrasonic cleaner. The drying operation was carried out using a Metaserv Specimen Dryer.

The specimen was polished using 6μ and 1μ grades of diamond polishing compound (Dialap) together with Dialap fluid or spray as a lubricant. the ¼μ diamond compound, Hyprez Spray, with Hyprez fluid spray was used for the final stage of polishing. The polishing was carried out on the polishing wheels of a Metaserv Universal Polisher.

The specimens were polished until they were mirror smooth and free from scratches. It was necessary to observe the specimen surface under the metallographic microscope from time to time during polishing. An optical microscope with incident illumination, the Olympus BHB microscope (Olympus Optical Co. Ltd., Japan) was used. It was found that for high-tin bronze specimens hand polishing was very difficult and took a longer time. An automatic polisher, the Metaserv Auto-Pol, was used together with the Universal Polisher in polishing the high-tin bronze specimens. In order to obtain the best results all the final polishing must be done by hand using ¼μ diamond paste on the polishing wheel of the Metaserv Universal Polisher.

For archaeological specimens, it was often found that it was difficult to remove the scratches from the polished surface of the specimen. The corrosion products in the grain boundaries or intergranular corrosion products tend to scratch the specimen surface during polishing. The specimen had to be cleaned thoroughly until it was free of lubricant which usually appeared as a stain on the surface.

2.9.5 Etching

It is necessary to apply an etchant to the surface. The etching reagents used for copper alloys are ammonium persulphate (25g in 100ml H_2O) and ferric chloride solution (100ml H_2O + 6ml conc. HCl + 20g $FeCl_3$). Before etching the specimen must be cleaned and dried thoroughly to prevent stains on the surface. Etching reagents will attack the surface of the specimen differentially to give the outlines of individual grains.

For very heavily corroded specimens a diluted etching solution (1:2) of ferric chloride was used in etching. The etching time was also shortened. It had been found that normal strengths of etching solutions were too strong for very corroded samples. For high-tin bronze specimens, normal strengths of ferric chloride solution gave a very good result in etching. The etching time for high-tin bronze specimens is around 15-20 sec. Some speciments need to be etched more than once before giving a satisfactory result. Ammonium persulphate was not used much in etching copper tin alloys in this project although it is claimed to give good results in bringing up the grain boundaries. After etching, the specimen must be rinsed to remove excess etching solution and dried under the specimen dryer.

2.9.6 Examination of the Specimen and Recording the Structure

An Olympus metallurgical microscope (BHB) was used in the examination of the microstructrue of the samples. Black and white photomicrographs of the microstructures were taken using the camera (C-35) attached to the microscope. The film used was Ilford Pan F (50 ASA). A photomicrographic exposure meter (Olympus EMM-7) was used in taking the photomicrographs. Colour photomicrographs of the microstructures were taken using the same equipment. The film used was Kodak Ektachrome (Tungsten balanced 50 ASA). To obtain the best results in colour photography, it was necessary to adjust the colour temperature before using the exposure meter. A light balancing filter LBD was used in the setting up.

2.10 EXPERIMENTS ON THE STRUCTURES OF QUENCHED STANDARD ALLOYS OF HIGH TIN BRONZE

2.10.1 The Preparation of Standard Alloys of High-tin Bronze

Alloys of 20, 23, 24, 25, 26, 27, 28, 30 wt% tin bronze were prepared.

Copper turnings (B.D.H. Chemicals Ltd., Poole, England) and tin powder (coarse) (East Anglia Chemicals, Hadleigh, Ipswich) were used in the preparation of the alloy.

Copper turnings and tin powder in the required amounts were weighed and then mixed in a silica crucible and graphite powder was put on the top of the metal before putting the lid in place. The crucible was placed in an electric furnace at 1100°C for 1 hour.

The melted alloy was then poured into a baked clay mould to form a cast bar. The dimensions of the cross-section were ~5x8mm; the length of the bar was about 8cm. Bars of copper-tin alloys of each composition were prepared in the same way. Each standard alloy bar was then cut into small pieces ready for the quenching experiments. A fast diamond wheel was used to section the bars.

2.10.2 Quenching of the standard alloys from different temperatures

The aim of this experiment was to compare the micro-structure of quenched standard alloys with the alloys found in antiquity, in order to deduce the heat treatment applied to the latter.

Small pieces of standard alloys of each composition were placed in a silica crucible; graphite was added to prevent oxidation before putting the lid on. The crucible was then placed in the electric furnace, which had been set to the temperature of 750^{o}C, for at least 2 hours to anneal the standard alloy.

Each piece of the standard alloys was then placed in a graphite crucible, covered with graphite, and the lid was put on. The graphite crucible was placed back in the furnace which was set to the required temperature for quenching. The samples were heated for around 1-2 hours (at least, depending on the size of the sample; for this experiment the sample size was about 5x8x5mm^3). The crucible was removed from the oven using iron tongs.

The standard alloy was then tipped from the crucible into a beaker of water at room temperature. The process of quenching from certain temperatures needs to be done as quickly as possible to obtain the quenching condition at the required temperature. The details of composition and quenching temperature prepared for heat treatment are summarized in Table 5.

The summaries of the microstructures found in each standard alloy are tabulated and presented in chapter 3.

2.11 MICROHARDNESS TEST

Indentation hardness was used in testing the specimens. This is a measure of the dimensions of an indentation produced by a standard hard indentor under standard load for a standard time (15 sec.).

A McCrone low load microhardness tester together with a Vickers diamond pyramid indentor was used in the measurements. The load used was 200g. The indentor was a diamond square-based pyramid which gives geometrically similar impressions regardless of the depth of penetration. The length of the impression's diagonal was measured in microns by means of a calibrated eyepiece graticule. The hardness value obtained from this type of indentor is called the Vickers hardness number, H_v. From the length of the diagonal of the impression and the load used, the Vickers hardness can be calculated from the following formula:

$$H_v = \frac{1854\ P}{D^2} \qquad kg/mm^2$$

where P = indenting load in grams = 200g

D = mean value of the impression's diagonal in microns.

The Vickers hardness of standard alloys quenched from different temperatures was measured and the results were presented in Table 6. The Vickers hardness of some ancient specimens was also measured; the data are presented in Table 7.

Measurements of microhardness of specimens can help not only in studying the properties of alloys, but also in the identification of different phases in multi-phase alloys. The value of the Vickers hardness number of the sample can be used with other information to explain the previous history of manufacture.

The Vickers hardness valuesof some high-tin bronzes in the as cast condition and after heat treatment are presented in Table 8 (adapted from Reeve, Bowden and Cuthbertson, 1953).

The same report also presented information on the heat treatment of a 25% tin bronze alloy which was quenched from the β-range and tempered. These quenched alloys were heated to 400°C, for varying periods of time with the object of decomposing the β-phase into the (α+δ) eutectoid. After tempering for 30 minutes, the hardness increased rapidly. After tempering for 4 hours, the Vickershardness reached a maximum of about 437 H_v. After tempering for 48 hours and upwards, the hardness value seems to be reduced and then to remain constant. The minimum value of the Vickers hardness is 357 H_v.

2.12 ELECTRON PROBE MICROANALYSIS

The principles of electron probe microanalysis (EPMA) are well known (Tite, 1972). The method has found extensive applications in the fields of geological and metallurgical analysis.

The machine used in the work in this thesis was the Cambridge Microscan 5 X-Ray Microanalyser, together with the Link Systems EDAX, provided with a ZAF correction program (Link System 860 model). This machine is in the Geology Department, University College, University of London.

The metallographic specimens, mounted in polyester embedding resin, which had already been polished on a succession of diamond pastes, were re-polished on ¼ micron diamond paste and placed in an ultrasonic cleaning bath in acetone for about 5 minutes. Standard specimens of pure elements were prepared in the same way, and both were given the same thickness of carbon coat in a Speedivac High Vacuum Coating Unit, Model 12 E6/1136, manufactured by Edwards High Vacuum Ltd.

The thinnest carbon coat compatible with the formation of a conducting layer (200Å -400Å) was used to coat both the standards and specimens. It was found that inclusions were not seen clearly through the optical system under a carbon coating. The colour of inclusions tended to change after coating and gave great difficulty in their identification.

Any particles of less than 1μ diameter cannot be analysed due to the limit of the electron beam diameter. For the identification of phases in the copper-tin alloys, there were no such problems.

In this project, the electron probe was used to identify the phases and the inclusions in the metallographic samples. The results have been reported in the catalogue (chapter 5).

The following example of the computer print-out from the machine is given for one analysis which was carried out on object no.1019, a wire, part of an ornament from Kok Khon.

```
 1019                                          LIVETIME(SPEC)=    100
 ENERGY   RES      AREA
-   5.8  100.28    68813
TOTAL AREA=   400183
......

FIT INDEX= 2.45

ELMT   APP.CONC   ERROR(WT%)
 SN     19.948       .231
 CU     78.243       .472
 CU     49.998       .788 NOT USED FOR ZAF
 PB       .055       .123* < 2 SIGMA*
 S        .064       .054* < 2 SIGMA*
 AS       .173       .067
 FE       .479       .076
 SB       .153       .223* < 2 SIGMA*
 NI   -   .028       .106* < 2 SIGMA*
 AG   -   .103       .123* < 2 SIGMA*
 AU       .206       .121* < 2 SIGMA*
 MN   -   .063       .070* < 2 SIGMA*

  [ 1 2 ZAF'S]

20.00 KV  TILT=  .00 ELEV=75.00 AZIM=  .00 COSINE= .000

SPECTRUM:  1019                                  3/8/81

ALL ELMTS ANALYSED

ELMT    ZAF     %ELMT
 SN     .875    22.789
 CU    1.020    76.762
 PB     .697      .079
 S      .934      .069
 AS     .386      .448
 FE    1.168      .410
 SB     .878      .174
 NI    1.066      .000
 AG     .876      .000
 AU     .662      .312
 MN    1.092      .000
TOTAL           101.042
```

TABLE 3

THE CONCENTRATION OF ELEMENTS IN STANDARD SOLUTIONS

	Standard Soln I		Standard Soln II		Standard Soln III		Standard Soln IV	
	PPM	%*	PPM	%	PPM	%	PPM	%
Cu	1000	100	800	80	700	70	600	60
Sn	5	0.5	50	5	150	15	300	30
Pb	2	0.2	10	1	50	5	150	15
As	0.2	0.02	0.2	0.02	2	0.2	20	2
Zn	0.5	0.05	1	0.1	5	0.5	10	1
Sb	1	0.1	5	0.5	10	1	20	2
Fe	50	5	20	2	10	1	1	0.1
Au	0.1	0.01	0.1	0.01	0.5	0.05	10	1
Ag	0.5	0.05	1	0.1	2	0.2	8	0.8
Ni	0.5	0.05	5	0.5	10	1	20	2
Co	0.5	0.05	5	0.5	10	1	20	2
Bi	0.5	0.05	5	0.5	10	1	20	2

*% of element in sample at concentration of 1 mg/ml.

TABLE 4

METAL ANALYSES BY ICP AND AA SPECTROSCOPY

Note: (a) Second copper analysis Cu(AA) obtained by Atomic Absorption spectroscopy.
(b) "-" signifies concentration below limit of detection.
(c) Difference value for copper may be invalid for corroded samples.
(d) "*" signifies slightly corroded object.
(e) "**" signifies heavily corroded object.
(f) "****" signifies no metal core remaining.

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
1005	105.879	87.598	3.933	0.114	0.098	0.128	0.016	0.053	0.012	0.005	-	-	110.238	95.641
1006	76.788	71.174	22.528	0.139	0.163	0.259	0.085	0.202	0.037	0.007	0.049	-	100.257	76.531
1008	91.848		2.25	0.812	0.177	0.155	0.021	0.069	0.027	0.006	0.018	-	95.383	96.465
1009	74.943		21.73	0.1741	0.256	0.181	0.197	0.065	0.028	0.006	0.016	-	97.596	77.347
1010**	86.625	66.194	4.106	0.449	0.079	0.107	0.059	0.046	0.017	0.003	-	-	91.491	95.134
1010**	76.208	45.249	3.795	3.210	0.302	0.108	0.101	0.144	0.016	0.025	-	-	83.909	92.074
1011**	83.577		8.72	0.137	0.104	0.134	0.123	0.036	0.014	0.005	0.019	-	92.869	90.708
1012**	92.620		10.344	0.189	0.112	0.034	0.034	-	-	-	-	-	103.333	89.287
1013*	71.616		29.314	-	0.048	0.031	0.246	0.202	0.012	-	0.017	-	101.485	70.131
1015**	67.211		2.982	-	-	0.0004	0.052	-	0.024	-	0.001	-	70.271	96.939
1016**	86.149		6.388	0.013	0.049	0.048	0.079	0.097	0.004	-	-	-	92.829	93.241
1017	72.870		22.68	0.151	0.228	0.188	0.271	0.073	0.400	0.005	0.010	-	96.876	75.994

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
1018A	77.000		21.63	0.143	0.309	0.170	0.067	0.129	0.027	0.004	0.067	-	99.548	77.454
1020A*	90.676	81.487	4.307	0.130	0.132	0.120	0.062	0.051	0.016	0.006	-	-	95.5	95.176
1020B	75.484	52.631	21.481	0.145	0.244	0.253	0.368	0.241	0.025	0.004	0.011	-	98.256	77.228
1021	74.690	62.238	22.428	0.127	0.256	0.249	0.066	0.214	0.024	0.006	0.038	-	98.098	76.592
1022	81.041		2.228	0.670	-	-	0.019	-	-	-	-	-	83.958	97.083
1023**	67.365		12.429	-	-	-	0.073	0.282	-	-	-	-	80.149	87.215
1026	92.429		3.88	0.695	0.183	0.165	0.024	0.050	0.028	0.004	0.012	-	97.47	97.281
1027B	98.524	78.740	5.936	0.471	0.197	0.147	0.033	0.041	0.023	0.005	0.023	-	105.40	93.124
1028	68.257	58.126	20.66	8.492	0.188	0.261	0.493	0.089	0.034	0.006	-	-	98.48	69.78
1029	67.816		7.71	27.863	0.226	0.151	0.046	0.081	0.023	0.004	0.024	-	103.944	63.872
1031	92.528		5.04	0.526	0.212	0.161	0.013	0.047	0.028	0.005	0.015	-	98.575	93.953
1034	87.727		2.94	0.953	0.202	0.128	0.017	0.034	0.023	0.004	0.016	-	92.044	95.683
1101**	87.969	77.268	6.797	0.627	0.141	0.144	0.224	0.039	0.018	0.006	0.016	-	95.981	91.988
1102*	80.146	64.368	15.182	6.277	0.651	0.235	0.090	0.209	0.076	0.012	0.171	-	103.049	77.097
1103**	49.878	43.679	25.590	0.153	0.051	0.238	0.101	0.010	0.015	0.006	-	-	76.042	73.836
1104**	69.973		6.719	-	-	-	0.058	-	-	-	-	-	76.750	93.223
1105	67.492		21.981	-	0.924	-	1.329	0.088	-	-	-	-	91.816	75.676
1106*	59.751		12.858	3.400	-	-	0.998	-	-	-	-	-	77.007	82.744
1108*	71.513	59.335	5.257	0.430	0.079	0.118	0.120	0.054	0.013	0.004	0.006	-	77.594	93.919
1109	87.892	73.125	11.927	2.526	0.187	0.236	0.017	0.104	0.031	0.005	0.010	-	102.747	84.956
1110	78.925		8.510	7.145	0.203	0.149	0.299	0.038	0.024	0.007	0.016	-	95.316	83.609

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
1111	82.193	69.324	8.999	15.113	0.578	0.325	0.039	0.206	0.056	0.012	0.061	-	107.582	74.611
1113**	72.778		2.959	0.074	-	-	0.166	-	-	-	-	-	75.978	96.800
1115	100.036	83.160	4.621	0.823	0.173	0.163	0.023	0.119	0.023	0.006	-	-	105.987	94.049
1116	77.159		5.65	10.831	0.731	0.188	0.071	0.068	0.053	0.007	0.096	-	94.854	82.305
1117	84.098	74.637	13.404	1.744	0.264	0.241	0.200	0.1004	0.031	0.007	0.036	-	100.125	83.973
1118	82.576	68.826	22.173	0.234	0.202	0.396	2.295	0.395	0.069	0.011	0.016	-	108.367	74.209
1119	75.366		22.041	-	0.781	-	2.295	0.145	-	-	-	-	100.629	74.737
1120*	84.685		9.549	3.268	0.107	0.034	0.160	-	-	-	-	-	97.803	86.882
1121A	90.065	79.051	7.853	3.456	0.296	0.242	0.028	0.131	0.039	0.008	0.023	-	102.141	87.924
1121B*	98.191	74.157	7.734	3.541	0.262	0.236	0.031	0.140	0.036	0.006	0.018	-	110.195	87.996
1123	91.880	94.25	2.356	0.726	0.167	0.145	0.048	0.052	0.028	0.008	-	-	95.410	96.470
1124	96.446	83.616	3.984	0.448	0.170	0.142	0.038	0.116	0.024	0.007	-	-	101.375	95.071
1125	91.014	78.387	9.724	3.717	0.254	0.235	0.055	0.100	0.037	0.006	0.012	-	105.154	85.86
1127*	95.915	77.02	7.904	4.917	0.210	0.222	0.191	0.179	0.030	0.007	0.020	-	109.595	86.32
1128*	94.385	74.603	8.206	0.419	0.106	0.165	0.062	0.075	0.027	0.009	0.025	-	103.479	90.906
1129A**	88.773	81.301	6.269	2.381	0.203	0.216	0.040	0.108	0.030	0.008	0.008	-	98.036	90.737
1129B	91.977	84.122	6.554	3.817	0.228	0.222	0.023	0.116	0.034	0.007	0.016	-	102.994	88.983
1129C*	88.284	79.475	6.471	2.088	0.257	0.232	0.078	0.126	0.036	0.008	0.006	-	97.586	90.698
1130*	99.356	79.848	5.872	3.074	0.190	0.192	0.074	0.101	0.033	0.005	-	-	108.897	90.459
1131A	84.749		7.16	0.321	0.134	0.145	0.024	0.038	0.021	0.004	0.018	-	92.614	92.135
1131B	82.489		7.44	16.856	0.227	0.174	0.036	0.067	0.025	0.006	0.024	-	107.344	75.145
1132	86.246	78.508	6.440	1.222	0.229	0.159	0.041	0.057	0.021	0.007	0.011	-	94.433	91.813

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
1133C**	89.958		6.547	0.117	0.030	-	0.054	-	-	-	-	-	96.707	93.252
1134	88.468	88.300	6.434	0.364	0.123	0.151	0.037	0.041	0.023	0.007	-	-	95.654	92.814
1135	98.792	82.543	7.609	0.438	0.190	0.164	0.085	0.041	0.023	0.005	0.022	-	107.369	91.423
1136B*	83.409		6.628	2.126	-	-	0.131	-	-	-	-	-	92.295	91.114
1137	83.176	98.379	3.856	0.325	0.154	0.135	0.049	0.031	0.019	0.008	-	-	87.753	95.423
1140**	65.097		10.258	10.004	0.196	0.352	0.113	0.769	0.008	-	-	-	86.798	78.299
1143	87.50	84.517	7.955	2.984	0.363	0.186	0.053	0.091	0.028	0.008	0.026	-	99.194	88.306
1145A	83.475	84.039	8.493	0.342	0.141	0.169	0.039	0.047	0.023	0.006	-	-	92.735	90.74
1145B	95.639	76.132	3.244	0.373	0.137	0.115	0.092	0.040	0.022	0.006	-	-	99.668	95.971
1901F	59.066		3.644	15.245	1.532	-	0.362	-	-	-	0.019	-	79.868	79.198
1901F**	48.54		2.55	4.826	0.581	0.093	0.636	0.060	0.015	0.004	-	-	57.305	91.235
1902C	76.410		9.65	8.725	0.499	0.163	0.340	0.098	0.036	0.008	0.034	-	95.963	80.447
1902G**	65.435		8.154	-	-	-	0.104	-	-	-	-	-	73.694	91.741
1903	56.978	52.419	14.932	0.200	0.403	0.150	0.271	0.013	0.037	0.011	-	-	72.995	83.983
1904A	76.575		23.39	0.126	0.121	0.164	2.22	0.008	0.026	0.024	0.024	-	102.679	73.897
1904B	78.110		21.67	0.114	0.193	0.157	0.132	0.009	0.016	0.004	0.018	-	100.423	77.687
1904C	79.442		22.32	0.144	0.172	0.194	0.991	0.009	0.022	0.012	0.029	-	103.335	76.107
1905A	101.129	79.150	7.626	0.127	0.193	0.149	0.108	0.097	0.028	0.010	0.030	-	109.497	91.632
1905B	80.218		21.19	0.169	0.188	0.170	0.087	0.029	0.030	0.004	0.007	-	102.092	78.126
1906A	104.509	92.391	6.506	1.094	0.181	0.205	0.061	0.088	0.028	0.006	0.017	-	112.695	91.814
1906B	85.755		11.99	1.322	0.134	0.165	0.038	0.129	0.022	0.006	0.019	-	99.58	86.175
1907	76.452		19.95	0.180	0.165	0.156	0.269	0.034	0.020	0.005	0.015	-	97.246	79.206

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
1911	-		6.37	0.151	0.053	0.132	0.018	0.158	0.009	0.005	0.012	-	6.908	93.092
1912A	82.153		12.57	7.332	1.562	0.359	0.113	0.311	0.080	0.02	0.519	-	105.019	77.134
1912B	91.924		2.22	0.660	0.127	0.132	0.029	0.025	0.017	0.004	0.011	-	95.149	96.775
1912C*	93.280		2.07	0.363	0.128	0.129	0.055	0.025	0.020	0.005	0.0072	-	96.082	97.198
1912E	92.165		8.67	0.392	0.203	0.147	0.048	0.023	0.023	0.005	0.008	-	101.68	90.481
1912G	92.301		4.37	0.772	0.201	0.144	0.017	0.035	0.021	0.004	0.023	-	97.879	94.413
1913B	92.394		5.77	0.225	0.159	0.144	0.086	0.023	0.022	0.004	0.017	-	98.844	93.55
1914A**	63.358	50.539	7.881	0.122	0.135	0.134	0.279	0.038	0.013	0.005	0.005	-	71.970	91.388
1914B*	69.583	62.263	8.291	0.136	0.084	0.138	0.226	0.020	0.017	0.007	-	-	78.502	91.081
1915A*	85.896	.	8.298	4.542	0.243	0.142	0.049	0.064	0.056	0.007	0.218	-	99.515	86.381
1915B*	83.917		7.73	4.588	0.220	0.140	0.063	0.070	0.051	0.005	0.230	-	97.014	86.903
1915C*	76.651	62.814	8.387	6.523	0.195	0.155	0.080	0.213	0.056	0.008	0.223	-	92.491	84.16
1201	99.322		7.776	-	-	-	0.080	0.204	-	-	-	-	107.382	91.939
1202	11.0393		-	-	-	-	4.775	-	-	-	-	-	15.814	95.225
1302	88.157		10.596	2.502	0.285	0.029	1.283	0.475	0.023	-	0.074	-	103.423	84.733
1305	73.873		10.519	16.130	0.422	0.016	0.561	0.088	0.019	-	0.073	-	101.704	72.169
1401**	7.334		-	-	0.039	-	22.537	-	-	-	-	-	29.916	77.423
1402**	88.319		7.227	-	0.049	0.019	0.137	0.534	0.043	-	-	-	96.329	91.990
1404	92.729		2.051	-	0.266	0.017	0.088	0.246	0.002	-	-	0.074	95.473	97.256

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
15001	83.279		9.710	0.717	0.097	0.151	0.138	0.018	0.013	0.005	0.013	-	94.141	89.138
15002	80.595		8.930	0.474	0.091	0.134	0.074	0.0150	0.012	0.003	0.007	-	90.335	90.26
15003*	81.114		8.120	0.520	0.088	0.130	0.100	0.015	0.011	0.0032	0.006	-	90.107	91.0068
15004	83.187		10.98	1.069	0.115	0.148	0.070	0.022	0.010	0.003	0.013	-	95.43	87.57
15005	81.997		10.26	1.063	0.12	0.148	0.039	0.020	0.012	0.003	0.019	-	93.681	88.316
15006	83.093		10.90	1.226	0.106	0.148	0.100	0.035	0.01	0.002	0.018	-	95.638	87.455
15007	81.694		10.67	1.054	0.130	0.151	0.057	0.019	0.013	0.004	0.032	-	93.824	87.87
15008	78.268		10.12	0.972	0.109	0.159	0.086	0.027	0.012	0.004	0.011	-	89.768	88.50
15009	72.543	76.547	10.069	1.061	0.163	0.180	0.073	0.046	0.019	0.009	-	-	84.163	88.379
15010	80.642		10.49	0.998	0.094	0.150	0.026	0.023	0.012	0.003	0.006	-	92.444	88.198
15011	88.460		10.75	0.837	0.107	0.143	0.075	0.015	0.011	0.003	0.012	-	100.413	88.047
15012*	77.379		8.59	4.479	0.147	0.142	0.057	0.071	0.020	0.005	0.027	-	90.917	86.462
15013	83.4		10.38	0.882	0.122	0.154	0.051	0.023	0.012	0.003	0.013	-	95.04	88.36
15014	93.623		11.60	0.97	0.134	0.152	0.089	0.017	0.011	0.004	0.018	-	106.618	87.005
15015	81.840		11.33	1.037	0.127	0.154	0.057	0.020	0.011	0.004	0.011	-	94.591	87.249
15016	82.374	79.124	2.237	12.287	0.561	0.548	0.016	0.378	0.080	0.012	0.004	-	98.497	83.877
15017	82.353		5.110	6.237	0.151	0.150	0.071	0.081	0.041	0.010	0.034	-	94.238	88.115
15018**	38.885		4.930	-	-	-	0.478	-	-	-	-	-	44.294	94.591
15019	81.200		5.619	16.801	0.363	0.199	0.033	0.227	0.033	-	-	-	104.474	76.726
15022	81.846	81.776	12.493	0.891	0.952	0.188	0.046	0.187	0.034	0.011	0.065	-	96.713	85.133
15023	78.644	78.585	11.349	13.372	0.246	0.232	0.025	0.160	0.028	0.008	0.015	-	104.079	74.565
15032**	56.998		4.059	-	0.066	-	0.292	-	-	-	-	-	61.416	95.582

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
15033**	48.145		6.339	-	0.008	-	0.495	-	-	-	-	-	54.987	93.158
15036	81.178		8.300	2.589	0.047	0.049	0.041	0.129	-	-	-	-	92.334	88.844
15037**	36.090		8.849	-	-	-	0.771	-	-	-	-	-	45.711	90.379
15038	83.858		6.02	0.246	1.743	0.168	0.060	0.143	0.040	0.004	0.140	-	92.422	91.436
15039*	68.620		7.244	-	0.014	0.005	0.146	-	-	-	-	-	76.029	92.590
15040**	48.449		4.857	0.085	0.002	-	0.034	-	-	-	-	-	53.427	95.021
15042*	42.012		5.009	-	0.037	-	0.514	-	-	-	-	-	47.572	94.439
15046*	86.476	76.775	8.335	0.158	0.080	0.161	0.062	0.073	0.034	0.012	0.015	-	95.406	91.07
15047**	43.561		4.772	-	0.023	-	0.143	-	-	-	-	-	48.499	95.062
15048	90.183		9.587	2.071	0.253	0.468	0.187	0.319	0.056	-	-	-	103.125	87.058
15050*	61.258	44.824	9.403	11.971	1.109	0.135	0.699	0.237	0.033	0.023	0.152	-	85.02	76.238
15051	91.636	87.461	0.582	11.455	0.826	0.488	0.013	0.380	0.151	0.008	0.018	-	105.557	86.079
15052	81.368	71.516	2.605	16.994	1.060	0.920	0.140	0.418	0.133	0.012	0.024	-	103.674	77.694
15053	85.818	82.412	10.538	0.133	0.134	0.175	0.039	0.257	0.099	0.032	0.012	-	97.237	88.581
15054	84.013	75.402	2.560	15.266	0.680	0.533	0.041	0.312	0.100	0.008	0.019	-	103.532	80.481
15057	78.042	74.621	6.416	16.687	0.151	0.149	0.030	0.077	0.018	0.006	0.018	-	101.584	76.448
15058	76.989	72.483	3.340	22.380	0.246	0.143	0.026	0.064	0.024	0.007	0.010	-	103.229	73.76
15059	82.064		6.262	12.724	0.074	0.051	0.036	-	-	-	-	-	101.210	80.853
15060	74.038	71.036	3.146	20.977	0.199	0.143	0.020	0.064	0.021	0.006	0.014	-	98.628	75.41
15061*	73.099		15.631	-	-	-	0.030	-	-	-	-	-	88.760	84.339
15062A	82.272	75.965	6.792	17.065	0.228	0.174	0.017	0.120	0.028	0.010	0.044	-	106.75	75.522
15062B	78.538	65.451	11.630	2.036	0.107	0.177	0.024	0.020	0.022	0.009	0.017	-	92.58	85.958

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
15063	86.204	85.347	7.601	7.054	0.228	0.194	0.012	0.080	0.029	0.009	0.025	-	101.436	84.768
15064**	24.953		23.829	0.729	1.444	-	0.079	0.467	-	-	0.253	-	51.753	73.200
15066	84.393	80.952	6.145	0.456	1.651	0.154	0.075	0.361	0.077	0.010	0.127	-	93.449	90.944
15068***	15.171		15.013	21.468	0.246	-	0.237	-	-	-	0.002	-	52.139	63.033
15069*	84.367		9.914	-	0.013	0.027	0.089	-	-	-	-	-	94.410	89.956
15070	81.309	73.308	7.856	17.368	0.167	0.165	0.035	0.208	0.020	0.008	0.054	-	107.19	74.119
15071	73.647		2.218	5.9349	-	-	0.303	0.384	0.021	-	0.105	18.374	82.612	72.766
15074*	86.038		9.294	0.257	0.013	-	0.146	0.277	0.088	-	-	-	97.113	89.925
15075	64.374		2.127	35.726	0.942	0.503	0.033	0.596	0.068	-	-	-	104.369	60.004
15075*	62.081		8.468	-	0.218	-	0.303	0.125	-	-	0.085	-	71.280	90.801
15076*	58.258	59.671	1.110	0.051	0.082	0.121	0.067	0.049	0.005	0.005	0.012	-	59.76	98.499
15077*	76.718		5.695	-	-	-	0.112	-	-	-	-	-	82.524	94.194
15078	94.549	66.924	7.055	1.361	0.446	0.176	0.029	0.419	0.049	0.010	0.134	-	104.228	90.321
15079	81.335	65.913	7.198	18.706	0.282	0.168	0.063	0.125	0.032	0.008	0.022	-	107.939	73.396
15080**	79.821		9.971	-	-	0.013	0.040	0.167	-	-	-	-	90.012	89.809
15081*	88.829		-	-	0.214	0.035	0.331	0.304	-	-	-	-	89.713	99.116
15085**	67.587		8.807	-	-	-	0.086	0.390	-	-	-	-	76.871	90.716
15086**	49.384		3.282	-	-	-	0.059	0.214	-	-	-	-	52.940	96.444
15087*	84.276		9.417	-	-	0.023	0.129	-	-	-	-	-	93.846	90.430
15088*	87.466		5.41	0.113	0.050	0.118	0.030	0.134	0.017	0.004	0.023	-	93.365	94.101
15089*	92.755		5.352	-	0.183	0.027	0.033	0.104	0.093	-	-	0.054	98.600	94.154
15090**	66.305		6.916	-	-	-	0.054	-	-	-	-	-	73.276	93.029

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
15091**	81.685		3.683	-	-	-	0.037	0.097	-	-	-	-	85.501	96.183
15092	93.773		5.222	-	0.066	0.002	0.017	0.235	-	-	-	-	99.316	94.457
15093	87.881		6.13	0.942	0.552	0.147	0.024	0.101	0.035	0.005	0.071	-	95.888	91.993
15094*	83.480		7.25	0.498	0.087	0.130	0.074	0.053	0.037	0.007	0.029	-	91.645	91.835
15095	93.659		6.259	-	0.072	0.039	0.036	-	-	-	-	-	100.065	93.594
15096**	71.712		6.222	1.985	-	-	0.361	-	-	-	-	-	80.279	91.432
15097**	61.080		4.045	-	0.002	-	0.291	-	-	-	-	-	65.419	95.661
15098**	44.219		7.913	-	-	-	0.314	-	-	-	-	-	52.446	91.773
15099**	56.619		8.700	-	-	-	0.122	-	-	-	0.0006	-	65.442	91.177
15101*	87.448		6.439	0.689	0.036	0.019	0.016	-	-	-	-	-	94.648	92.799
15103	81.378		6.405	4.03	1.580	0.743	0.015	0.135	0.059	0.010	0.023	-	94.378	87.0
15104	72.995		4.871	-	0.029	0.013	0.029	-	0.027	-	-	-	77.964	95.031
15105A**	73.653		8.433	0.008	0.466	0.035	0.189	-	-	-	0.019	-	82.805	90.848
15105B*	88.049		-	-	1.057	0.049	0.014	-	-	-	-	0.056	89.226	98.823
15107*	82.687		8.388	-	-	0.028	0.065	-	-	-	-	-	91.167	91.519
15108	85.212	84.885	7.414	0.334	0.949	0.169	0.052	0.232	0.058	0.013	0.073	-	94.506	90.706
15109*	79.651		11.114	-	0.093	0.029	0.007	0.027	-	-	-	-	90.921	88.730
15110*	57.355	63.191	7.381	0.104	0.079	0.130	0.413	0.176	0.021	0.007	0.003	-	65.669	91.686
15111**	38.635		7.699	-	-	-	0.961	-	-	-	-	-	47.295	91.34
15112	86.014		9.899	-	-	-	0.128	-	-	-	-	-	96.041	89.973
15113**	70.626		2.504	-	-	-	0.081	-	-	-	-	-	73.211	97.415
15114*	65.030	62.50	5.055	0.091	0.077	0.116	0.023	0.123	0.009	0.006	0.011	-	70.541	94.489

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
15118*	83.759		11.376	-	0.037	0.017	0.006	0.346	-	-	-	-	95.543	88.216
15136***	30.365		13.433	-	-	-	0.476	-	-	-	-	-	44.273	86.091
15215*	76.379		9.281	0.206	0.940	0.039	0.114	0.353	-	-	0.101	-	87.414	88.965
16001***	26.631		2.372	-	-	-	0.202	0.627	-	-	-	-	29.832	96.799
16002	96.464		0.157	9.129	0.065	0.118	0.051	0.340	0.012	0.002	0.021	-	106.359	90.105
	96.758		-	8.787	0.110	0.105	0.049	0.323	0.012	0.002	0.014	-	106.162	90.596
16003**	40.799		0.754	-	-	-	0.358	-	-	-	-	-	41.912	98.888
16004	89.907		14.099	0.197	0.078	0.036	0.209	0.281	0.049	-	0.025	-	104.881	85.026
16005*	74.359		7.051	0.158	0.035	0.041	0.237	0.278	0.030	-	-	-	82.189	92.169
16006***	8.845		0.797	-	-	-	0.456	-	-	-	-	-	10.094	98.751
16007***	57.914		0.981	-	-	-	0.093	-	-	-	-	-	58.988	98.926
16008	61.084		7.646	-	-	-	0.131	0.096	0.001	-	0.016	-	68.974	92.114
16009***	53.826		1.436	-	-	-	0.083	-	-	-	0.017	-	55.363	98.463
16010***	1.878		-	-	-	-	0.329	-	-	-	-	-	2.207	99.671
16011	-		24.357	94.904	0.073	0.434	0.065	0.247	-	-	0.052	-	120.133	-
16012***	21.285		-	8.494	-	-	0.230	0.043	-	-	-	-	30.052	91.233
16013***	9.543		7.928	-	-	-	0.443	-	-	-	-	-	17.914	91.629
16014	68.778		16.019	26.117	0.073	0.021	0.058	0.234	0.012	-	0.024	-	111.336	57.442
16015**	82.085		3.398	11.439	0.470	0.029	0.111	0.348	0.027	-	0.065	-	97.974	84.112
16016**	69.824		5.460	4.012	0.806	0.068	0.186	0.148	0.034	-	0.136	-	80.675	89.148
16017***	12.619		5.438	-	-	-	0.176	-	-	-	0.033	-	18.267	94.352

TABLE 4 (continued)

Lab.No.	Cu	Cu (AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
16018*	62.691		10.627	13.609	0.449	0.115	0.091	0.338	0.021	-	0.089	-	88.029	74.661
16019	89.897		3.129	1.164	0.030	0.027	0.069	0.153	0.017	-	0.012	-	94.498	95.399
16020	75.905		5.919	9.009	0.105	0.037	0.069	0.069	0.009	-	0.009	-	91.134	84.771
16021	71.896		7.808	1.1663	0.772	0.006	0.064	0.341	0.019	-	0.064	-	82.137	89.759
16022*	70.065		11.898	8.119	0.221	0.077	0.109	0.406	0.023	-	0.1001	-	91.019	79.045
16023***	41.288		2.789	-	-	-	0.453	-	-	-	-	-	44.53	96.758
16024	93.867		3.958	0.746	0.058	0.041	0.048	0.538	0.013	-	0.051	0.015	99.336	94.531
16025	91.501		8.511	2.387	0.219	0.080	0.046	0.102	0.026	-	0.008	0.025	102.906	88.595
16026	77.197		10.179	4.069	0.526	0.109	0.077	0.344	0.034	-	0.111	-	92.648	84.549
16027*	74.274		8.427	8.858	0.129	0.062	0.109	0.201	0.014	-	0.011	-	92.087	82.187
16028*	64.681		9.936	15.353	0.803	0.116	0.070	0.104	0.037	-	0.183	-	91.285	73.396
16029***	55.078		6.703	0.007	-	0.034	0.134	0.198	-	-	-	-	62.155	92.924
16030***	43.502		2.952	-	-	-	0.199	0.023	-	-	-	-	46.676	96.826
16031***	52.219		11.456	-	-	0.021	0.093	-	-	-	-	-	63.789	88.431
16032***	59.394		7.002	-	0.005	0.016	0.277	0.222	0.004	-	0.009	-	66.929	92.464
16033***	28.257		0.982	-	-	-	0.248	0.121	-	-	-	-	29.609	98.648
16034***	57.372		12.106	0.091	0.045	0.062	0.101	0.077	-	-	-	-	69.855	87.517
16035**	-		-	-	-	-	3.145	-	-	-	-	-	3.145	-
16036***	55.285		9.578	0.193	-	0.002	0.061	-	0.008	-	0.008	-	65.135	90.149
16037***	55.333		14.024	-	-	0.051	0.058	-	-	-	-	-	69.467	84.866
16038	96.678		1.148	0.720	0.049	0.037	0.058	0.157	0.013	-	0.015	0.005	98.881	97.798
16039**	56.053		15.776	3.240	0.271	0.066	0.163	0.021	0.039	-	0.063	-	75.693	80.359

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
16040**	56.668		4.677	-	-	-	0.207	-	-	-	-	-	61.552	95.116
16041***	33.812		5.876	1.233	0.032	0.003	0.207	-	-	-	-	0.057	41.222	92.590
16042***	24.633		12.357	-	0.013	-	0.291	0.052	-	-	0.445	-	37.391	87.242
16043***	20.237		8.983	-	-	-	0.765	0.002	-	-	0.008	-	29.996	90.241
16044	75.342		8.137	22.107	0.165	0.095	0.057	0.387	0.030	-	0.011	-	106.331	69.011
16045***	48.366		14.265	0.042	0.016	0.087	0.176	-	0.009	-	-	-	62.962	85.404
16046	92.619		4.248	0.255	0.078	0.064	0.054	0.164	0.018	-	0.015	0.0230	97.538	95.081
16047***	56.642		14.928	0.022	-	0.051	0.061	-	-	-	-	-	71.704	84.938
16048***	42.132		3.929	-	-	-	0.208	0.164	0.001	-	0.017	-	46.451	95.681
16049***	54.934		8.556	-	-	-	0.265	-	0.034	-	0.012	0.077	63.877	91.057
16050**	39.212		0.049	2.303	0.082	-	0.138	-	-	-	-	-	41.784	97.427
16051***	32.309		8.694	3.098	0.039	-	0.416	-	-	-	-	-	44.566	87.753
16052***	52.813		14.621	-	-	-	0.005	-	-	-	-	-	67.439	85.374
16053***	54.681		5.040	0.215	0.097	-	0.065	-	-	-	-	-	60.099	94.582
16054***	37.202		12.248	-	-	-	-	-	-	-	-	-	49.450	87.752
16055***	68.012		0.925	4.599	0.036	-	0.059	-	-	-	-	-	73.632	94.379
16056***	49.145		18.272	0.234	0.017	-	0.815	-	-	-	-	-	68.484	80.660
16057***	52.118		3.132	6.124	0.018	-	0.326	-	-	-	-	-	61.719	90.399
16058	91.564		6.404	1.099	0.056	-	0.064	-	-	-	-	-	99.188	92.376
16059	82.189		9.145	10.977	0.202	-	0.405	0.022	-	-	-	-	102.939	79.249
16060***	50.061		5.582	-	-	-	0.080	-	-	-	-	-	55.723	94.338
16061***	66.279		4.968	-	-	-	0.007	0.007	-	-	-	-	71.261	95.018

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
16062***	43.627		20.888	-	-	-	-	-	-	-	-	-	64.516	79.112
16063***	53.629		14.318	-	-	0.124	0.023	-	-	-	-	-	68.095	85.534
16064	62.057		29.455	-	0.109	0.012	3.598	-	0.009	-	-	-	95.242	66.815
16065***	38.137		7.796	-	-	-	0.124	-	-	-	-	-	46.058	92.079
16066***	57.724		4.824	-	-	-	0.008	-	-	-	-	-	62.556	95.167
16067***	44.711		26.999	-	-	-	0.088	-	-	-	-	-	71.799	72.912
16068***	62.411		6.461	-	-	-	0.005	-	-	-	-	-	68.878	93.533
16069	59.132		20.210	-	-	-	0.023	-	-	-	-	-	79.366	79.766
16070***	57.304		0.491	-	-	-	1.984	-	-	-	-	-	59.779	97.525
16071***	91.558		4.854	-	3.557	-	0.067	-	-	-	-	-	100.037	91.521
16072***	60.799		5.944	-	-	-	0.017	-	-	-	-	-	66.760	94.039
16073***	42.709		11.660	0.568	-	0.035	0.008	3.761	-	-	-	-	58.743	83.967
16074	73.003		12.028	12.831	0.136	0.511	0.021	-	-	-	-	-	98.530	74.473
16075***	55.507		0.855	0.704	-	-	0.119	-	-	-	-	-	57.186	98.320
16076***	48.806		10.362	-	0.166	-	0.221	0.092	-	-	0.020	-	59.667	89.139
16077***	53.060		4.593	6.090	0.130	-	0.050	-	-	-	-	-	63.924	89.136
16078***	72.684		3.559	-	-	-	-	-	-	-	-	-	76.243	96.441
16079***	39.930		3.602	-	0.787	0.049	0.086	-	-	-	-	-	44.455	95.475

TABLE 4 (continued)

Lab.No.	Cu	Cu(AA)	Sn	Pb	As	Sb	Fe	Ag	Ni	Co	Bi	Zn	Total	Cu(100-x)
18001	84.964		26.777	-	-	0.063	0.011	0.538	-	-	-	-	112.354	72.611
18002	75.057		24.933	-	0.059	-	0.141	-	0.026	-	-	-	100.217	75.294
18003	74.572		21.026	0.476	0.025	-	0.214	1.023	-	-	-	-	97.336	77.236
18004	85.693		3.473	15.506	0.1305	-	1.153	0.346	0.145	0.017	-	-	106.464	79.229
18005	67.274		7.997	25.655	0.169	-	0.118	0.321	0.116	-	-	-	101.652	65.622
18006	73.630		23.214	-	0.011	0.037	0.049	1.527	-	-	-	-	98.469	75.161
18007	71.235		21.829	-	0.269	0.055	0.399	-	0.163	0.048	-	-	94.0005	77.235
18008	70.004		22.189	0.291	0.037	0.013	0.033	1.230	-	-	-	-	93.798	76.206
18009	76.436		8.860	10.833	0.229	0.027	0.006	0.486	0.167	-	-	-	97.045	79.392
18010	62.826		31.254	-	0.002	0.059	0.068	0.766	-	-	-	-	94.973	67.852
Bucket (handle)	68.147		10.593	21.946	0.227	-	0.378	0.388	0.188	0.096	-	-	101.964	66.182
Bucket (base)	44.461		7.170	13.254	0.096	-	0.379	0.105	0.098	0.040	-	-	65.604	78.857

TABLE 5

The detail of composition, the time for homogenization at 750°C and the quenching temperature of standard alloys.

Alloy wt % Sn	Time for homogenization at 750°C (hours)	Quenched from temperature of °C
20	1	750
		650
		550
		450
23	2	750
		650
		550
		450
24	2	750
		650
		550
		450
25	3.15	750
		650
		600
		550
		450
26	19	725
		650
		550
27	19	725
		650
		550
28	19	725
		600
30	19	725

TABLE 6

VICKERS HARDNESS VALUES OF STANDARD ALLOYS

Description of Object	Area of Hardness Measurement	Hardness $H_v = \frac{1854P}{D^2}$	Average of Hardness
Standard Alloy 20wt% Sn quenched from 650°C in water	β-needle (acicular) overlapped with α-phase	131.01 131.01	131.01
	α-phase only	108.28 103.52	105.9
	β-needle (acicular) area only	161.75 249.25 171.12	194.04
Standard Alloy 20wt% Sn quenched from 750°C in water	β-needle (acicular) area only	171.119 181.333 204.708	185.72
	β-needle (acicular) overlapped with α-phase	137.818 181.333 153.12 153.12	156.35
	α-phase only	131.01 113.37 118.83	121.07

TABLE 6 (continued)

Description of Object	Area of Hardness Measurement	Hardness $H_v = \frac{1854P}{D^2}$	Average of Hardness
Standard Alloy 23wt% Sn quenched from 650°C in water	β-needle (acicular) phase	149.50 185.49 165.46	166.82
	β-needle overlapped with α-phase	140.98	140.98
Standard Alloy 23wt% Sn quenched from 750°C in water	β-needle (acicular) phase only	218.13 198.46 232.66	216.42
Standard Alloy 24wt% Sn quenched from 650°C in water	β-needle (acicular) phase only	218.13 218.13 218.13	218.13
Standard Alloy 24wt% Sn quenched from 750°C in water	β-needle (acicular) phase only	204.71 192.49 204.71	200.64
Standard Alloy 25wt% Sn quenched from 650°C in water	Banded martensite (β') area. (long markings in the large grains)	249.25 232.66 204.487 217.893	226.07
	Other areas of the grains without banded martensite	232.66 249.25 225.339	235.75
Standard Alloy 25wt% Sn quenched from 750°C in water	Banded martensite (β')	232.91 232.91 204.71 232.91 218.13 218.13	223.28

TABLE 7

VICKERS HARDNESS VALUES OF ANCIENT SPECIMENS

Sample No.	Area of Hardness Measurement	Hardness H_v
1109	α-solid solution	67.0995
1110	" "	79.2365
1911	corroded α-solid solution	61.763
1910B	corroded α-solid solution	42.77
1901D	α-solid solution	131.259
1131B	" "	82.824
1124	" "	68.133
1105	part of α and β phase	221.5495
1901C	α-solid solution	101.2905
1915A	" "	73.255
1912H	α-solid solution	88.756
1135A	" "	70.159
1116	α phase and eutectoid	73.712
1136A	α-solid solution	80.634
1904A	banded martensite (β')	335.394
1017	β-martensite	227.984
1125	partially corroded α solid solution	79.057
1018B	β-martensite	223.707
1119	β-martensite	250.143
1019	β-martensite	204.911
1006	β-martensite	287.547
	α-solid solution	56.745
1912B	α-solid solution	51.463
15071	α-solid solution	76.667
1904B	α phase and β-martensite	208.137
1028	α-solid solution	164.273
1906B	α-solid solution	102.14

TABLE 8

HARDNESS OF HIGH TIN BRONZES IN AS-CAST CONDITION AND AFTER HEAT TREATMENT

	Vickers Hardness Number					
Tin Content Percent	As-cast Condition	Annealing at 700°C for 2 hours	Annealing at 700°C for 24 hours	Annealing from the $\alpha+\beta$ range or between 586-798°C and quenching	Annealing in range (750°C) for 24 hours and quenching	Annealing at 575°C and quenching
15	145	108 the redistribution of the delta phase resulting from the break up of the eutectoid				
20	209		235 the precipitation of the epsilon phase	190 the softening is attributed to some retention of the beta phase		
25	351				236 softening is because of some retention of beta phase	292 structure is alpha plus gamma
28	437					

NOTE: For as-cast condition, hardness increases with tin content. The content of ($\alpha+\delta$) eutectoid also increases with tin content.

3. MICROSTRUCTURAL CHARACTERISTICS

A large proportion of the artifacts obtained from different sites in Thailand (see chapter 1) have been studied by the techniques of optical metallography and chemical analysis. The alloys used in manufacturing these artifacts can be classified into the following main groups: pure copper; the binary alloy low-tin bronze (the composition range of tin in this alloy is up to around 16.5wt% tin); the binary alloy high-tin bronze (the composition range of tin in this alloy is from 16.5wt% upwards); and the ternary alloy leaded tin bronze. The metallographic structures of these alloys will be described in this chapter.

3.1 THE METALLOGRAPHIC STRUCTURE OF PURE COPPER

As the metal apart from impurities contains only one kind of atom, the structure is that of a single phase. The basic pattern in the microstructure of normal metals is the cell-like arrangement of polyhedral grains or crystals. The dimensions of these grains range from 0.01 to 50 mm. or larger, depending on the condition of the metal (Bailey, 1972,3).

The solidification of molten metal is a process of crystallisation and results in the formation of a polycrystalline mass. In the first stage a few atoms arrange themselves in a geometrical pattern characteristic of the metal, and as they solidify give up to their surroundings a part of the energy which made it possible for them to move freely through the liquid. These clusters of atoms therefore become relatively stable and serve as the crystal nuclei to which other atoms become attached in the same geometrical pattern to form crystals. During the second stage of crystal growth the crystals feed upon the molten metal by attracting other atoms to their space lattices and throw out arms into the surrounding liquid. Other arms grow from these first arms and form branches, which in turn throw out spines of their own. This method of growth results in the formation of crystal skeletons which resemble pine branches, and which therefore are called dendrites. As solidification progresses, the space between the branches becomes completely filled to form a solid crystal. Eventually adjacent crystals meet and interfere with each other. The contact zone between adjacent grains is called the grain boundary. The grains appear as equiaxial grains under the optical microscope (Shrager, 1969; Cottrell, 1975).

3.1.1 The cast structure of copper

Casting is the process of pouring molten metal into a prepared mould cavity which has the shape of the object to be made. When the metal solidifies, an object which has approximately the same shape as the mould will be obtained.

The process of solidification has been described in section 3.1. The typical structure of pure metal in the as-cast condition can be long columnar grains, or equiaxial grains. If the molten metal is poured into a relatively cold mould, the result is long crystals radially perpendicular to the surface of the mould, pointing in toward the centre of the mould. In the solidification of a casting of large cross section the central portion of the metal freezes independently of any chilling action, and equiaxial grains form. Often equiaxial grains may occur throughout the section. The presence of soluble impurities or alloying elements often causes the formation of equiaxial grains in the casting (Bailey, 1972).

The size of the crystals, either columnar or equiaxial grains, increases with the casting size and the pouring temperature of the metal. The rate of cooling is also of great importance because it governs the size, shape and arrangement of the grains of a metal casting. If the cooling rate is slow, the resulting structure is coarse grained. If the cooling rate is rapid, as in the case of thin castings, or if the metal is poured into chilled moulds, solidification starts at a greater number of different points and a larger number of grains develop, producing a finer grain structure. In modern metallurgy it is very important for practical reasons to produce uniform, equiaxial, fairly fine crystals in large castings, for this structure gives metal with the best strength and other mechanical properties. Some solute is added to the metal (nucleating agent) to promote as much nucleation as possible in the liquid for the solidification process.

3.1.2 The microstructure of cold worked pure metal

Cold working is plastic deformation carried out below the recrystallization temperature. Cold working is usually carried out on previously cast and annealed metal. The characteristic of the microstructure of metal after cold working is that the grains are distorted and show evidence of residual strain in the form of grain distortions and strain lines within the grains. There is elongation of the grains perpendicular to the working direction. The metal becomes harder and the ductility is lost.

When metals are cold worked and then annealed above the recrystallization temperature, a new set of strain-free grains (equiaxial grains) forms in the solid state by the process of recrystallization. Twin lines also occur in the grains of face-centred cubic metals which were deformed by cold working and then annealed.

Inclusions in the metal after cold or hot working are usually arranged perpendicular to the direction of working. When the inclusions are relatively plastic, they become elongated in form. If they are brittle, they tend to be broken up into smaller angular pieces. In the latter case, insoluble inclusions remain angular in shape. They may subsequently become more rounded in shape, especially if the deformed metal receives prolonged heating.

3.1.3 The microstructure of hot worked pure metal

Hot working is the plastic deformation of a metal at a temperature above its recrystallization temperature.

The characteristic microstructure of hot worked metal is the same as the microstructure of metal cold worked and then annealed.

3.2 THE BINARY ALLOY LOW TIN BRONZE

Pure copper is a soft metal. The property is partly governed by slip and dislocation in the metal. The arrangement of atoms in the space lattice of a metal is a determining factor in slip. Copper, which crystallizes in the face-centred cubic form, has twelve planes of easy slip. A soft metal offers little resistance to deformation because slip is produced readily. Dislocations are inequalities of crystal structure which permit slip to take place more easily. Metal with wide dislocations can slip easily and is therefore soft. Copper, aluminium and gold are extremely soft because of wide dislocations.

One method of improving the hardness is to block the dislocations. Alloying introduces foreign atoms, which form clumps that offer resistance to slip. Work hardening, by which a metal acquires resistance to further slip, is caused by the creation of new dislocations. When there is a sufficient number of these they move along intersecting slip planes, obstructing one another's movements, and preventing further slip (Shrager, 1969). Due to the above causes, alloying of copper with tin produces a harder metal.

3.2.1 The equilibrium diagram of the copper-tin system, and phases occurring in the system

The equilibrium diagram is a graph of composition against temperature, showing the limits of composition and temperature within which the various constituents or phases of an alloy are stable. From this diagram information concerning the structure and composition of the constituents of an alloy at each temperature can be predicted.

A copper-tin alloy is a binary alloy, in which two metals, copper and tin, are partially soluble in each other in the solid solution. Because copper cannot dissolve tin continuously in the solid solution, there are several phases which occur at different compositions and temperatures. These phases, which are usually named by Greek letters, differ greatly in their properties.

There are many equilibrium diagrams of the copper-tin alloy system proposed by many authors. Some of these diagrams are presented in fig. 3 (Raynor, 1944), fig. 4 (Smith, 1967), and fig. 5 (American Society for Metals, 1973).

The information on the crystal structures of the phases of the copper-tin system is mainly extracted from the work by Pearson (1958, 611-614). The equilibrium diagram of the copper-tin system used in this thesis is taken from Hansen and Anderko (1958). The equilibrium diagram which they published is the work of Raynor. Most of this diagram (Raynor, 1944) is accurate but some doubt still exists over the exact form of the β and γ areas and the positions of their boundaries. Also, the precise termination of the boundary between the α and $(\alpha+\varepsilon)$ fields towards room temperature is not known and is therefore shown as a dotted line in the diagram.

The α-phase, which is a solid solution, has a face centred cubic structure. The crystal structure is type A2. The α-phase extends to a maximum of ~9 at% (atomic %) Sn (15.8 wt% Sn).

The β-phase is an electron compound. The composition of this phase is around 15 at% Sn (24.8 wt% Sn). The β-phase forms peritectically at 798^{o}C and decomposes at 586^{o}C. The β-phase, stable at high temperatures, has a body centred cubic A2 type of structure. The composition of the β-phase corresponds approximately to Cu_5Sn.

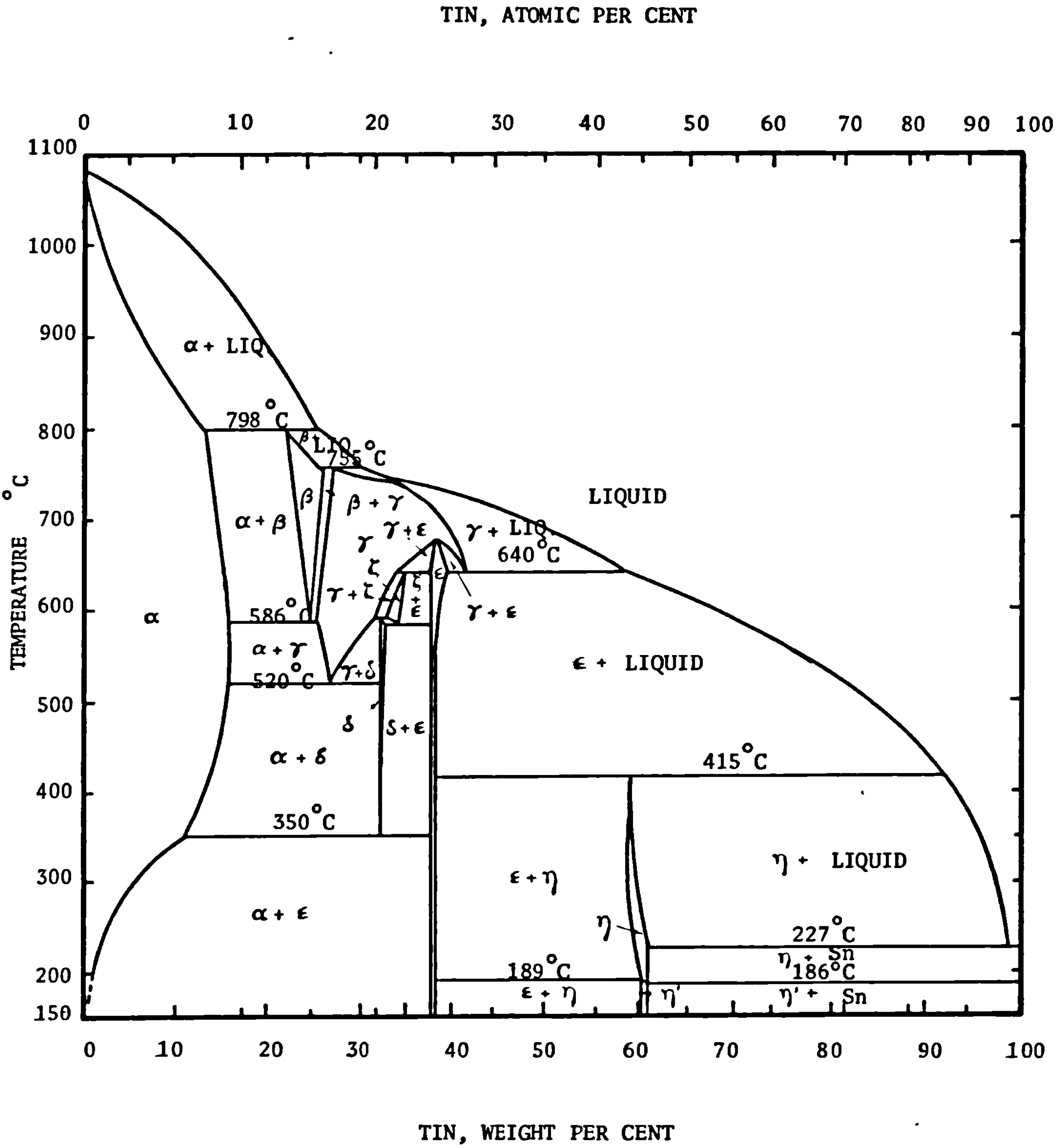


Fig. 3 The tin-copper equilibrium diagram, after Raynor.

The γ phase is also an electron compound. The composition range is around 15-28 at% Sn (24.8-42.1 wt% Sn). The γ phase forms peritectically at 755°C and decomposes at 520°C; it has a wide range of stability. The γ-phase is stable only at high temperatures. It has been reported that the crystal structure is type DO_3, the crystal symmetry is an ordered face centre cubic structure and the formula is ~Cu_3Sn. Westgren and Phragmen, calling the phase β', reported that it could not be retained by quenching. Hansen and Anderko reported the information obtained by many researchers about the crystallographic similarity of the β and γ phases. The fact that both phases decompose on quenching, forming a metastable transition structure, is probably responsible for the various forms of phase relation suggested by Hansen (1936).

The δ-phase is also an electron compound. The composition of this phase is around 20.5 at% Sn (32.5 wt% Sn). This phase forms peritectoidally at ~585°C and decomposes at 350°C; it has a very narrow range of stoichiometry. It has a cubic structure similar to the $D8_{1-3}$ γ-brass type, and contains ~416 atoms per unit cell. It is frequently accorded the formula $Cu_{31}Sn_8$ although this does not agree exactly with the number of atoms estimated for the unit cell (Peason, 1958, 612-613). The δ-phase decomposes into the eutectoid (α+ε) at a temperature reported as around 350°C (see the equilibrium diagram by Raynor fig.3). This transformation occurs extremely slowly especially in massive specimens. For most purposes, δ can be considered as stable below 350°C (Hansen and Anderko, 1958, 635).

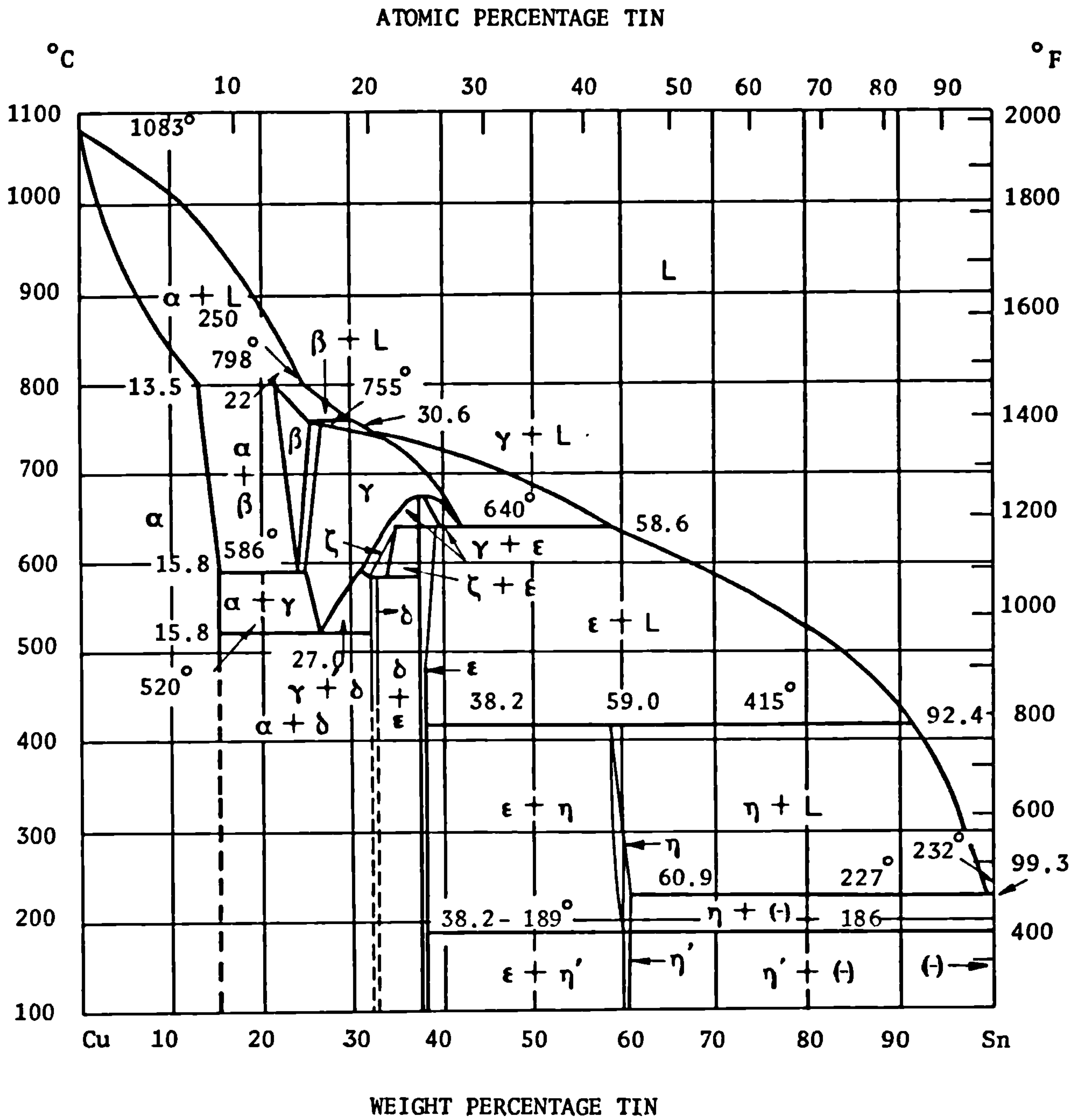


Fig. 4 Constitution diagram for copper-tin alloys. The dotted lines below 450°C show the conditions to be expected under normal metallurgical treatment; under true equilibrium conditions additional changes would occur. (From C.S. Smith, "The Interpretation of Microstructures of Metallic Artifacts," in Application of Science in Examination of Works of Art/Boston: Museum of Fine Arts, 1967./)

The composition of the ζ-phase is approximately 22 at% Sn (34.5 wt% Sn). It forms peritectoidally and is stable between 640°C and ~585°C. It has a trigonal structure. The ideal formula is $Cu_{20}Sn_6$.

The ε-phase is an electron compound. The composition is approximately 24 at% Sn (37.1 wt% Sn). It forms from the γ-phase at ~675°C and is stable down to room temperature. The approximate formula is Cu_3Sn and it has a pseudo-hexagonal A3 type of unit cell which may possibly be the true unit cell. It has been reported that the ε-phase is very difficult to obtain. When the α-phase is annealed for a long time below 350°C (1,000 hours), a metastable ε-phase first precipitates and later changes to a stable form (Cuthbertson, 1960).

The composition of the η-phase is approximately 43 at% Sn (~58 wt% Sn). It forms peritectically at 415°C and transforms to η' at ~188°C. The ε-, η- and η'- phases each have a narrow composition range (Raynor, 1944).

The structure of the η- and η'- phases have been studied. The structure of the η'-phase is that of a hexagonal pseudo cell, the formula being Cu_6Sn (Carlsson and Hägg, 1932; Gernal, 1928). The structure can be regarded as a superlattice of the NiAs (B8) type structure. Since the alloys featured in this thesis are not in the η range, the information above on the η and η' phases will not be discussed further.

The equilibrium diagram gives information on the phases which are thermodynamically stable at any particular composition and temperature. It shows the phases which should exist during cooling in equilibrium conditions (on slow cooling).

PHASE DIAGRAMS OF BINARY ALLOY SYSTEM

Cu-Sn Copper-Tin

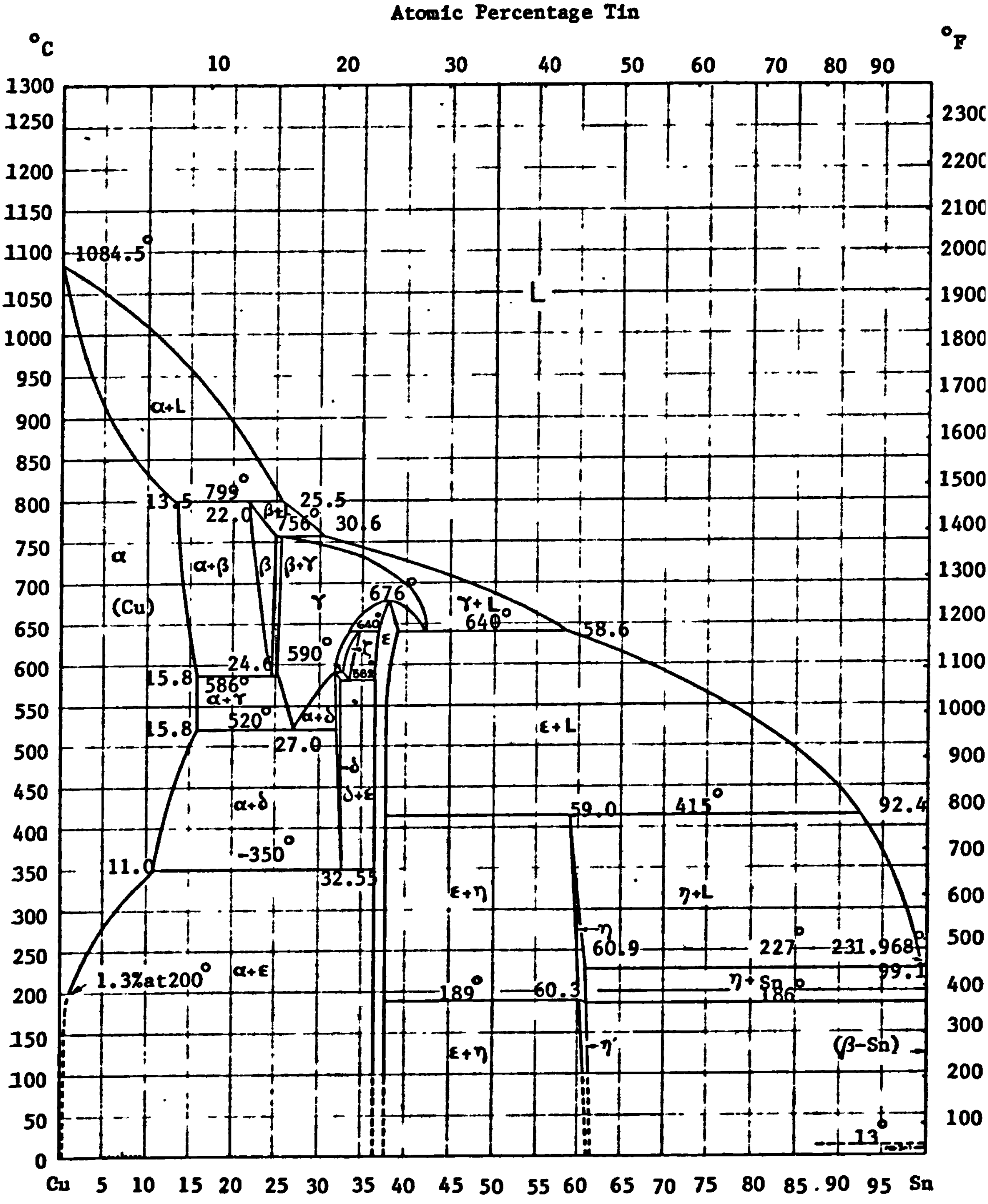


Fig. 5

Weight Percentage Tin

In practice it is very difficult to control the slow cooling process. When a liquid solution of an alloy is allowed to cool slowly the phase stable at a high temperature will transform to the phase stable at a lower temperature. By rapid cooling (quenching), the phase stable at a high temperature can often be retained (see section 3.3).

3.2.2 Microstructures commonly found in low tin bronzes

The composition range of this binary alloy is up to around 17 wt% Sn. From the equilibrium diagram, the α-phase solid solution exists up to a maximum amount of 16.2 wt% Sn at 520°C. At room temperature, a pure α-structure can be obtained in an alloy containing up to around 13 wt% tin (Cuthbertson, 1960). The α-phase has the properties of softness and ductility. Mechanical working can be applied to this type of alloy very easily. However, in practice the brittle δ-phase appears about 7 wt% tin in sand castings and above 5 wt% tin in chill castings (Bailey, 1975).

The δ-phase is hard and brittle, and its presence in duplex alloys has a pronounced effect on their properties, which are dependent on the distribution of this constituent. The increase in δ-phase increases hardness and tensile strength, but can cause brittleness if it is present as an inter-crystalline film between the α-grains.

3.2.2.1 The as-cast structure

The microstructure obtained by casting is usually a dendritic structure. Slowly cooled castings will have equiaxial grains. As mentioned in 3.2.2, the phase expected in an alloy of not more than 5 wt% tin is the pure α-phase.

The α-dendritic structure will appear together with the ($\alpha+\delta$)-euctectoid when the tin content increases. Cast bronze containing more than 5 wt% tin will always contain some δ-phase unless it is annealed at the appropriate temperature, and then quickly cooled. The equilibrium diagram (fig.3) shows the wide separation of the liquidus and solidus. This means that there will be a large difference between the composition of the liquid and solid in equilibrium at any temperature. When alloys containing less than 16 wt% tin solidify below the liquidus temperature, the α-phase starts to crystallize out of the melt. When the temperature drops to the peritectic temperatures of 799°C and 586°C, the β phase and γ phase may respectively separate from the melt.

The β- and γ-phases are both metastable, they transform to ($\alpha+\delta$)-eutectoid on further cooling below 520°C. The final structure is an α-dendritic phase in the ($\alpha+\delta$)-eutectoid. The amount of ($\alpha+\delta$)-eutectoid will increase as the tin content increases.

An α-dendrite in an as-cast low tin bronze is usually a cored dendrite (Lab.no.1023). The rate of solidification during casting is very important. For the binary alloys, if the rate of cooling is rapid there will be cores in the dendrites. Cored grains occur because the original dendrites are richer in copper than the surrounding solution, so the composition of the melt, and the solid crystallizing from it, changes gradually. When the temperature drops very quickly, the diffusion rate of copper from the starting dendrite (nucleus) cannot keep pace with the growth of the grain. If the molten metal is slowly cooled, diffusion within the grain occurs and coring will not be seen. (This means that the system of solidification is in equilibrium.)

Cored grains can be altered by annealing. Cored grains never happen in pure metal because the composition of the metal is homogeneous and there is only one metal in the system.

In casting, there are several problems which often occur. They are shrinkage, segregation and gas evolution (lab.no. 1005 and lab.no.1029). The cast metal is likely to have some degree of porosity as a result of shrinkage or gas evolution from the molten metal during solidification. Coring, which is mentioned above, is one form of segregation.

Inclusions are also found in cast metal. They are found in the form of insoluble particles of oxide, sulphide or slag material. Inclusions may be found within the grains or at the grain boundaries. The details of inclusions will be discussed in section 3.5.

3.2.2.2 The cold worked structure

The definition of cold working has already been discussed in section 3.1.2. The cast alloy of low-tin bronze is usually mechanically worked. It is possible to cold work the α-alloy (i.e. the alloy containing only α-phase), but the presence of any δ-phase impairs workability. For modern tin bronze, the cold working of this alloy is limited to alloys containing not more than 7 wt% tin. Alloys containing up to 15 wt% Sn can be cold worked, although less easily than lower tin alloys, which are softer. The alloys containing more than 16.5 wt% Sn cannot undergo cold working; they must be heated into the β and γ ranges to permit working. The details of working high tin bronze will be discussed later.

Cold working increases the tensile strength of all the α-alloys. It is the accepted method of obtaining the highest strengths in alloys which cannot be hardened by heat treatment (Cuthbertson, 1960, 396).

The characteristic of the microstructure of the cold-worked copper-tin bronze is the same as the cold-worked pure metal for the single phase alloy. The alloy containing less than 5 wt% tin will have only α-phase. The alloy containing 5 wt% Sn upwards may contain more than one phase such as the α-phase and (α+δ)-eutectoid. The phases will show deformation perpendicular to the direction of working. Only the longitudinal section can illustrate this point clearly (Bailey, 1972, 32). If the cast alloy of low-tin bronze has not been annealed, the dendritic structures will still remain but they will be distorted dendrites. If the cast alloy has been annealed long enough after working, equi-axial grains will appear with twin bands inside the grains (see also section 3.1.2).

3.2.2.3 The hot worked structure

The definition of hot working has been given in section 3.1.3.

The α-copper-tin alloys can generally be hot worked, but all require very careful treatment. In modern practice the hot working of α-copper-tin alloys is mainly restricted to alloys containing not more than 7 wt% tin. Other than for α-alloys, hot working is mainly performed on alloys containing from 20 to 25 wt% tin. The appearance of δ-phase in the alloy outside the pure α- phase range is the main difficulty. Although heating makes the δ-phase more plastic and improves the workability of the alloy, there is another tendency which is detrimental to hot working. The α-phase becomes less ductile as the temperature is raised and impurities in the alloy have a far more damaging effect on ductility than in cold working (Cuthbertson, 1960). It has however been reported that all bronzes containing up to 25 wt% Sn and free from impurities such as bismuth and lead can be hot rolled. Furthermore, low-tin bronzes can be hot-worked from 850°C downwards.

The characteristic microstructure of hot working is the same as that of cold working followed by annealing (see also section 3.2.2.2).

3.2.2.4 The heat treated structure

Cast bronzes are usually not in equilibrium. The structure of α-bronze is likely to be cored, and δ-phase may be present even when the tin content is as low as 5 wt% (see section 3.2.2.1). Heat treatment permits diffusion within the dendrites that eliminates the cored structure, and the dendritic structure may disappear with prolonged annealing. If the cast alloy has been annealed long enough, equiaxial grains will appear, with twin bands where the sample has been worked.

The effects of heat-treatment on the mechanical properties of binary bronzes were first investigated some time ago

(Guillet, 1905; Shepherd and Upton, 1905). Hanson and Pell-Walpole (1951) found that homogenization of cored, wholly α-bronze, containing up to 5% of tin, by annealing at 550°C or 650°C, only affected the elongation values, which fell slightly below those of the cast alloys. The annealing of bronze containing from 5 to 15% of tin in order to "dissolve" the δ-phase improves tensile strength and elongation and decreases hardness. He also reported that the tensile strength reached a maximum at 15 wt% tin, and the elongation at 12 wt% tin. Above these compositions the values of both properties decreased considerably.

If the tin content increases to 25-30 wt% tin, a higher tensile strength can be obtained by quenching from 650°C or 550°C to retain the β-phase or γ-phase respectively. Tempering of the alloy of 15-20 wt% tin at 300-400°C after quenching increases hardness and reduces tensile strength and elongation to lower values than those for the cast alloys. Ageing the same alloy at normal temperatures following quenching causes the tensile strength to fall to the highest value for the α-phase.

For the high-tin bronze alloy, 20-25 wt% tin, similar results are obtained, but as the tin content increases, the strength decreases rapidly and the hardness increases for a given heat treatment. Hanson and Pell-Walpole (1951) also reported that permanent improvement in mechanical properties is obtainable by quenching from 550°C or 650°C only in alloys containing 5 to 15 wt% tin. In higher-tin alloys no heat treatment will give a long-lasting strength greater than that obtainable in the 15 wt% tin alloy, and the elongation values are much lower. Quenching followed by tempering can greatly increase the hardness of high-tin alloys, but brittleness may increase to such an extent as to cause spontaneous cracking through residual internal stress.

3.3 THE BINARY ALLOY OF HIGH-TIN BRONZE

The composition range of high-tin bronze strictly extends from 15.8 wt% tin (9.13 at%) upwards; see the equilibrium diagrams figs. 4 and 5. It can be conveniently defined as having a tin content from 17 wt% tin (9.88 at%) upwards. The β-phase appears in the (α+β) region (13.5 wt% tin or 7.71 at% tin at 799°C to 24.6 wt% or 14.87 at% at 586°C). The region of pure β-phase is between the alloy of 22 wt% tin (13.11 at%) at 799°C and around 25 wt% tin (15.14 at%) at 756°C. The region of (β+γ) phase is between 24.6 wt% tin (14.87 at%) at 756°C to 25.5 wt% tin (15.48 at%) at 586°C. There is a slight difference in temperature and composition for these phases in Pearson's (1958, 1967) opinion. The β-phase (~15 at% Sn or 25 wt% Sn) forms peritectically at 798°C and decomposes at 586°C. The γ-phase (~15-28 at% Sn or 24.8-42.1 wt% Sn) forms peritectically at 755°C and decomposes at 520°C.

The phases appearing in high-tin bronzes are the α-phase, β-phase, γ-phase and δ-phase, depending on the content of tin. These phases have been described in section 3.2.1. The α-phase and δ-phase are stable at room temperatures, the β-phase and γ-phase are stable at high temperatures. As described in section 3.2.1 the phases appearing in an alloy at each temperature can be predicted by using the phase diagram together with the known composition of the alloy.

The majority of the alloys of high-tin bronze found in the objects being studied in this thesis contain 20-25 wt% tin (11.8-15.14 at% tin). There are very few objects containing more than 25 wt% tin, and none more than 30wt% tin (18.66 at% tin). The alloy of 20-25 wt% tin can be called a β-bronze.

The following sections will be concerned with the high temperature β-phase and the quenched phases in copper-tin alloys. Before starting this topic, it should be pointed out that the experimental work undertaken was only such as proved necessary to identify the ancient alloys and fabrication technique used, and optical metallographic techniques were largely used. No fundamental studies of the structures were undertaken, as these do not fall within the scope of the present project.

SUMMARIES OF THE SYMBOLS OF MARTENSITES USED IN THIS THESIS AND USED BY OTHER AUTHORS

Symbols used in this thesis	Explanation of the symbol	References	Symbols used by other authors
β	β-phase at high temperature, body centred cubic (b.c.c) structure (disordered)	Nishiyama, Morikawa and Shimizu (1967)	β
β_1	β-phase at high temperature, b.c.c structure (ordered)	Nishiyama, Morikawa and Shimizu (1967	β_1
		Warlimont (1965)	β_1
β_2	the retained beta phase at room temperature, after quenching, appearing as matrix in the original β- grain	Warlimont (1965)	β_1
		Nishiyama, Morikawa and Shimizu (1967)	β_2
		Kennon and Miller (1972)	β_1
β_1'	martensite of acicular, needle like structure including coarse needles. It is an ordered long-range stacking structure, faulted.	Kurdyumov (1948)	β'
		Warlimont and Härter (1965)	β'
		Isawa (1936)	β'
		Isaychev (1939)	β'
		Lobodyuk, Tkachuk and Khandros (1970)	β'
		Warlimont (1965)	β_1'
		Kennon and Miller (1972)	β_1'

Symbols used in this thesis	Explanation of the symbol	References	Symbols used by other authors
β_1'	The collective name for acicular needle like structures where the crystal structure is a lamellar composite of the structure β_1' and γ_1' Under the optical microscope the appearance of this lamellar type of martensite is the same as the normal acicular needle martensite.	Warlimont (1963)	β_1''
		Warlimont and Härter (1965	β_1''
		Kennon and Miller (1972)	β_1'
β'	The banded martensite which has long thin markings similar to strain lines. This martensite is obtained by quenching the copper-tin alloy from β-phase region into water at room temperature or 0^oC.	Nishiyama, Morikawa and Shimizu (1968)	β'
		Kennon and Miller (1972)	β'
		Shimizu, Sakamoto and Otsuka (1975)	β_1'
β''	The wedged martensite which can be obtained by cooling of the quenched alloy in the liquid nitrogen. The crystal structure is ordered orthorombic, twinned.	Kurdyumov (1948)	β''
		Isaytchev (1936)	β''
		Soejima, Hagiwara and Nakanishi (1966)	β''
		Morikawa, Shimizu and Nishiyama (1968)	β''
		Warlimont (1965)	γ_1'
		Warlimont and Härter (1965)	γ_1'
		Kennon and Miller (1972)	γ'

3.3.1 The β-phase (high temperature)

The β-phase is stable only at high temperatures. It is metastable at room temperature and transforms on slow cooling. The β-phase can be retained to some extent by quenching from the temperature at which it is stable (see section 3.3.2, the quenched β-phase). The retention of an appreciable amount of β-phase is difficult to achieve and especially so if the tin content of the alloy is less than about 20 wt% (Cuthbertson, 1960).

The β-phase has a body centre cubic (b.c.c), A2 type of structure (Pearson, 1958). From the experiments by Nishiyama and Morikawa (1967), a new crystal structure of β-phase at high temperatures has been proposed. Apart from having the b.c.c structure, it also shows the structure of DO_3 type superlattices (Fe_3Al type). They also reported that there are transformations of ordered β phase (β_1) to disordered β phase (β) between the temperatures of 725°C and 750°C.

Nishiyama, Morikawa and Shimizu (1967) examined the structure of an alloy containing 24.5 wt% tin quenched from 700°C in iced water. The quenched alloy was studied and it was found that it was a β-martensite (β') in the shape of long thin straight markings (banded martensite) associated with the matrix of the retained original parent β grain (β_2, retained β phase).

The beta martensite (β') will be discussed in detail in the next section.

From the electron diffraction pattern the matrix (the original parent β-grain) consists of the retained phase (β_2)

and the precipitated α, δ or η phases. It seems that the retained phase obtained by quenching is partly tempered by beam heating in the electron microscope. On the basis of the phase diagram, the β_2 or retained beta phase should be the only component in the matrix of this type of quenched alloy.

The structure of the retained phase (β_2) untempered is basically of the Fe_3Al type, but it has a long period which is 3 times as large as the (110) spacing of the latter. This period has tentatively been interpreted using a model which is formed from the Fe_3Al type lattice (β_1) by substituting Cu atoms for Sn atoms lying on every third (100) layer.

The appearance of the retained beta phase (β_2) in the electron micrograph of the 24.5 wt% Sn binary alloy (low magnification micrographs not given in this paper) seems to be similar to the result of the experiments on quenching 24 wt% tin and 25 wt% tin-bronze carried out for this project (see the metallographic photographs of these alloys and the photograph from the Nishiyama et al. paper, p.149, pl.3).

V.A. Lobodyuk, V.K. Tkachuk and L.G. Khandros (1970) state that for Cu-Sn alloys in the composition range 23.5-27% Sn sudden quenching from temperatures above 650°C delays disintegration of the high temperature β phase. There is a partial martensitic transformation in the process of cooling to room temperature in the example of the 24.5% Sn alloy. The amount of martensite decreases as the concentration of tin increases, and a pure β-phase is preserved in alloys containing more than 25.5 wt% Sn.

From personal experimental observations, in binary alloys of 25, 26 and 27 wt% Sn, the amount of martensite decreases with increasing Sn content and the amount of retained β-phase increases.

In alloys of 23% and 24% tin quenched from 720°C and 650°C there is much more martensite than in 25, 26 and 27 wt% alloy. The amount of martensite in 27 wt% tin alloy quenched from 725°C is less than in 26 wt% tin alloy quenched from 720°C and 650°C. The 26% tin alloys also have less martensite than 25 wt% tin bronze quenched from 720°C and 650°C. In 28 wt% tin bronze, there are no martensitic structures visible in the alloy.

3.3.2 The quenched structure in high-tin bronze

As mentioned earlier, the high tin bronze alloy is rather brittle due to the appearance of δ-phase in a large quantity. Cold working of high-tin bronze is not possible but hot working can be performed if the alloy of between 20-30 wt% tin is worked in the β- or γ-phase temperature range (Cuthbertson, 1960). The β-phase can be retained by quenching from the temperature at which it is stable. The properties of quenched β-phase have been described in section 3.2.2.4. The β-phase will martensiticly transform into β-martensite during the quenching process. The retained β-phase (β_2) also appeared, and could be seen very clearly in alloys of certain compositions (Nishiyama, Morikawa and Shimizu, 1967).

3.3.2.1 Review of research on the martensitic structure of high-tin bronze

Isawa (1936) stated that β-phase alloys containing less than 25 wt% Sn transformed to β'-phase on quenching from above 600°C, but alloys containing 25-27 wt% Sn gave the β-phase itself. (In recent publications, this term "β-phase" itself has been called the retained β-phase or β_2-phase; see Morikawa, Shimizu, Nishiyama, Trans JIM, Vol.8, 1967.)

Isaychev (1939) also reported that β-phase alloys containing 23.6 to 25 wt% Sn transformed martensitically to a β'-phase on quenching but the structure of β' martensite was not studied.

Lobodyuk, Tkachuk and Khandros (1970) reported that in the 23.5-27 wt% Sn alloy sudden quenching from temperatures of approximately 650° delays disintegration of the high temperature β-phase. The partial martensitic transformation occurs and the amount of martensite decreases as the concentration of tin increases and a pure β-phase (retained high temperature β-phase = β_2) is preserved in alloys containing more than 25.5 wt% tin.

Kurdyumov (1948) has established that 2 martensite phases, namely β' (banded martensite) and β" (wedge shaped) martensite are formed, depending on the composition of the copper-tin alloy. As the tin content approaches 24.6 wt% there is an increase in the amount of β' phase. Above 25.2 wt% tin, the amount of β" phases increases. In between 24.6 wt% and 25.2 wt% both phases are formed.

Nishiyama, Morikawa and Shimizu (1968) reported two types of martensite in the alloy of 24.5 wt% Sn, that is, the banded β' martensite obtained by quenching from 700°C into water at 0°C and wedge-shaped β" martensite obtained by further cooling to a lower temperature. They also published an optical micrograph of the 24.5 wt% tin alloy quenched from 700°C into water at 0°C. This micrograph shows line (band) markings which are martensite crystals, described by them as β_1(see also the photographs of the 25 and 26 wt% Sn alloys quenched from 750°C as part of this present work). They also examined the β banded martensite under the transmission electron microscope (see their Photo 2a, 3a, 4a and 5a). These electronmicrographs showed a martensite band embedded in the matrix of the retained β phase (β_2). Each of such bands corresponds to one of the line markings in their Pl.1. All over the band, many striations (the average spacing about 100Å) are seen, most of which are due to stacking faults. The authors also studied the crystal structure of β' martensite, which they found to be an orthorhombic close-packed lattice of AB'AC' type. In the electron micrograph, striations parallel to the (122) plane are found. These striations and the elongation of diffraction spots perpendicular to them show the existence of stacking faults (spacing about 100Å) due to the martensitic transformation. The orientation relationships between the β' martensite and the parent β_1-phase are $(001)_{\beta'}//(110)_{\beta_1}$ and $[\bar{2}\bar{1}0]_{\beta'}//[\bar{1}11]_{\beta_1}$, the habit plane of the β' martensite plates being near $(\bar{2}2\bar{3})_{\beta_1}$.

Shimizu, Sakamoto and Otsuka (1975) use the symbol β_1' for banded martensite instead of β' which was used by previous researchers. The reason was that the structure is ordered and is analogous to the β_1 martensite in the Cu-Al system. Their major points may be summarized as follows:

(1) The banded martensite β_1' was obtained by quenching the 24.5 wt% tin alloy into water at 0°C.

(2) The same alloy was cooled down to study whether the martensite was growing in amount or changing its morphology. There were no changes in the amount and shape of β_1' banded martensite until the temperature reached -140°C. At -140°C the wedge-shaped 2H type martensite (β") reported by Nishiyama, Morikawa and Shimizu (1968, 317) appeared.

(3) It can be concluded that the martensite which appeared with cooling in the present alloy is wedge shaped martensite, 2H type (β") but that the martensite called β_1' is induced by stress upon quenching.

(4) The β_1' martensite may also appear on cooling below 0°C if the tin content is much lower than 24.5 wt%. Warlimont and Härter (1966, 453) reported that the β' martensite appears in the composition range of 13.1-<14.0 at% Sn (21.97-<23.32 wt% Sn).

(5) There is a slight difference in microscopic morphology between the β_1' formed by cooling below 0°C and the β_1' induced by quenching stress. The former is an aggregate of martensites constituting a self-accommodating system, while the latter appears as individual acicular martensite separated by the matrix (see fig.1 in Warlimont and Härter, 1966).

(6) A new structure was also proposed for banded martensite. The same alloy of quenched 24.5 wt% Sn bronze was examined by means of the electron microscopy and electron diffraction experiments performed on selected areas:

(a) The crystal structure of the banded martensite was found to be a β' 18R type, long period stacking order structure with a stacking sequence of AB'CB'CA'CA'BA'BC'BC'AC'AB'.

(b) The internal defects of the martensites were stacking faults on the basal plane.

(c) The habit plane of the martensites was close to the $(\bar{1}\bar{4}4)$ $\beta_1$plane, consistent with the result of Greninger and Mooradian, which was determined by two-surface analysis in bulk specimens.

(d) The orientation relationship between matrix and martensite was consistent with the Kajiwara-Nishiyama relationship found in a thermally formed β_1' Cu-Al martensite. This is their reason for using the symbol β_1' to describe banded martensite.

Warlimont and Härter (1966) reported that the martensitic transformation of the disordered β(b.c.c) and ordered β_1 (Fe_3Si type b.c.c superlattice) high temperature Cu-Sn phases was studied using electron microscopy and electron diffractions. Three types of martensite sturcture were studied.

β' martensite which is shown in their fig.1 page 454 consists of thin parallel-sided plates which are internally faulted. It corresponds to the β' martensite in Cu-Al system. The stacking sequence is derived from ABC of the f.c.c lattice by faulting into ABC/BCA/CAB/AB due to the lattice invariant deformation.

β_1'' martensite forms as thin plates which are internally lamellated (see fig.2 in their paper). β_1'' is a composite of 2 crystal structures. One of these structures is very similar to that of β' and is the only one recognizable by x-ray diffraction. The other one has not been clearly identified. The occurrence of β_1'' is related to an increasing deviation from close packed structures with increasing Sn content. This deviation may be expressed in terms of the splitting of characteristic reflections like 202 and $12\bar{2}$.

γ_1' (see fig.4 in their paper). Their γ_1' martensite is called wedge-shaped martensite β" by many researchers. It forms at a lower temperature during liquid nitrogen cooling below -140^{o}C. γ_1' forms as thick plates. It is an internally twinned martensite whose basic crystal structure has been determined previously (Isaychev, 1947). The twins appear internally considerably deformed, possibly by faulting (Nishiyama, Shimizu and Morikawa, 1965).

In this paper the authors also proposed the composition ranges of β', β_1" and γ_1' martensites in the copper-tin alloy system. The β' martensite will be found in copper-tin alloys containing 13.1 - <14.0 at% Sn or 21.97 - <23.32 wt% Sn.

β" martensite will be found in alloys containing 13.8-15.0 at% Sn or 23.02-24.8 wt% Sn. γ_1' martensite will be found in alloys containing >14.5 at% Sn or 24.06 wt% Sn.

Miller and Kennon (1972) reported the phases which form with increasing Sn concentration in the Cu-Sn system. These phases are given the same names as Warlimont used;

a. β_1'-ordered long-range stacking structure with faults.

b. β_1"-lamellar composite of the structure β_1' and γ_1'.

c. γ_1'-ordered orthorhombic twinned (some researchers call this phase wedge martensite and give β" as the symbol. The details of wedge martensites will be discussed later).

The β_1' and β_1" martensites, which can be distinguished only by electron metallography (Warlimont, 1965), form during quenching from temperature above some minimum given as 590^{o}C by Carson (1929) and 650^{o}C by Isaitchev (1939). The γ_1' martensite forms at lower temperatures during liquid nitrogen cooling.

The banded martensite β' is produced by water quenching, but wedge-shaped β" martensite can only be formed by sub-zero cooling of the same alloy after quenching.

Isaytchev (1936; 1947) found orthorhombic martensites in quenched 25.5 wt% Sn alloy cooled in liquid nitrogen.

Soejima, Hagiwara and Nakanishi (1966) also concluded on the basis of their X-ray data that lens-shaped martensites in 24.8 wt% Sn alloy obtained by cooling in liquid nitrogen have an orthorhombic structure (a=4.558Å, b=5.402Å, c=4.358Å).

The optical micrographs of banded martensites were described in the previous section. The same authors Morikawa, Shimizu and Nishiyama (1968) also studied the effect of cooling the quenched 24.5 wt% Sn bronze in liquid nitrogen at -196°C. The structure of line band markings of the quenched alloy was transformed suddenly giving rise to wedge-shaped relief on the surface as shown in their photographs 1(b) and 1(c).

Kennon and Miller (1972) also showed a photomicrograph of surface relief associated with γ_1' martensite in 25.08 wt% Sn alloy (see photograph 3 in their article). These authors also show a typical example of an electron micrograph showing the inner part of a wedge-shaped β" martensite which has a structure consisting of fine lamellae (Kennon and Miller, 1972, p.318, pl.2). Every other lamella has a similar appearance, but the adjacent ones differ from each other.

In this photograph the alternate lamellae have a width of about 100Å and several hundred Å respectively. They are twin-related with each other. Each twin lamella has abundant striations whose directions are the same in the twins of the same kind. Such striations are contrasted due to stacking faults.

The crystal structure of β'' martensite was studied by Morikawa, Shimizu and Nishiyama using an electron microscope on Cu -24.5 wt% Sn alloy. From the diffraction patterns it is found that the β'' martensite has a close-packed orthorhombic structure of AB' stacking (or 2H type stacking ordered structure). Its structure consists of lamellae parallel to the (121) plane, and spots due to the (121) twin are observed in the diffraction pattern. From these facts it is concluded that the β'' martensite has twin faults due to the transformation. Moreover there are finer striations within the lamellae. These striations are thought to be contrasts of stacking faults parallel to $(1\bar{2}1)$ planes. The crystal orientation relationships between the β'' martensite and the parent phase β_1 are $(001)_{\beta''}//(110)_{\beta_1}$ and $[\bar{2}10]_{\beta''}//[\bar{1}1\bar{1}]_{\beta_1}$.

The wedge-shaped β'' martensite in Cu-Sn alloys has never been found in ancient alloys. The details of this type of martensite will not be discussed further here.

3.3.2.2 The microstructure of quenched high-tin bronze

The experiments in quenching the standard alloys from different temperatures were carried out to compare the metallographic structures with the work of other researchers and as a basis for evaluating the structures of the ancient metal artifacts studied. The experimental details have been described in section 2.10. A summary of the results is presented here:

20 wt% Sn: Annealing time 2 hours; Quenched from 750°C; Large α-dendritic structure on background of β-martensite (coarse short needle). (Pls.9-12)

20 wt% Sn: Annealing time 2 hours; slightly hot worked; Quenched from 750°C; Twinned α (α still remaining in large dendritic form) in a background of β martensite (coarse short needles). (Pls.13-16)

20 wt% Sn: Annealing time 2 hours; Quenched from 650°C; Large dendrites radiating from the central part of the specimen in a background of β-martensite needles. (Pls.17,18)

20 wt% Sn: Annealing time 2 hours; Quenched from 550°C; Large α-dendrites radiating from the centre of the specimen in a gray background. (Pls.19,20)

20 wt% Sn: Annealing time 2 hours; Quenched from 450°C; Large α-dendrites radiating from the centre of the specimen in an eutectoid (α+δ) duplex structure. (Pls.21,22)

23 wt% Sn: Annealing time 3 hours; Quenched from 750°C; There are β_1' needle martensites in very thin and long shapes. There are also short needles which look very compact. The needles lie parallel in some areas and discontinuity in their patterns clearly highlights the original β phase grain boundaries. This structure showed the very large β-phase grain size. (Pls.23-26)

23 wt% Sn: Annealing time 3 hours; Quenched from 650°C; Very small α-phase regions on background of thin long β-martensite needles. The long β-martensites are still shorter than in 23 and 24 wt% Sn bronze quenched from 750°C. In some areas α-phase forms along the original β (high temperature) grain boundaries. There are also some areas showing the large original β grain sizes. The β-martensite needles form in between α-phase regions. The length varies depending on the gap between the α-phase regions. These β martensite needles look rather compact. (Pls.27-29)

<u>23 wt% Sn:</u> Annealing time 3 hours; Quenched from 550°C; α-phase in gray background which may be the incompletely decomposed γ-phase or even δ-phase. The α-phase had started forming a Widmanstätten structure. (Pls.30,31)

<u>23 wt% Sn:</u> Annealing time 2.15 hours; Quenched from 450°C; α-phase in the form of thin leaf-like areas in background of eutectoid structure. The α-phase regions form Widmanstätten structures in a background of δ-phase (blue). (Pls.32,33)

<u>24 wt% Sn:</u> Annealing time 3 hours; Quenched from 750°C; Needle-like structure of β-martensites. The needles are very long and also parallel to each other in some areas. The large grains of original β-phase still appear very clearly. There are some short needles which are compact. (Pls.34,35)

<u>24 wt% Sn:</u> Annealing time 2 hours; Quenched from 650°C; Almost entirely a martensitic structure. Most of the needles are long, although some short, compact, needles are present. A little α-phase is present, especially along the original β grain boundaries (but less α-phase than in the 23 wt% Sn alloy quenched from 650°C). (Pls.36,37)

<u>24 wt% Sn:</u> Annealing time 1.15 hours; Quenched from 550°C; The α-phase seems to form a Widmanstätten structure on a background of gray colour [should be β_2 (new symbol) or γ (old symbol)]. (Pls.38,39)

<u>24 wt% Sn:</u> Annealing time 2.15 hours; Quenched from 450°C; α-phase leaf-like structures in a blue background of δ-phase together with small α-phase regions. The α-phases seem to form a Widmanstätten structure. (Pls.40,41)

<u>25 wt% Sn:</u> Annealing time 4 hours; Quenched from 750°C; There are large grains of high temperature β-phase on which a lot of thin markings of β banded martensite fill the grains. The needles are thin and long, much thinner than the needles in 23 and 24 wt% tin bronzes. (Pls.42-44)

<u>25 wt% Sn:</u> Annealing time 1 hour; Quenched from 650°C; Large grains may be high temperature β-phase and β' banded martensite is seen in the grain. The interesting point is that not many thin markings form in this specimen, and they mostly form on the edge. (Pls.45-47)

<u>25 wt% Sn:</u> Annealing time 1.20 hours; Quenched from 600°C; The amount of thin markings is less than in 750°C and 650°C. The needles tend to follow the grain boundaries. (Pls.48-50)

<u>25 wt% Sn:</u> Annealing time 1.20 hours; Quenched from 550°C; There are very small α-phase precipitates along the original large grains (may be γ-phase). The α-phase seems to form a Widmanstätten structure in the gray background. (Pls.51-52)

<u>25 wt% Sn:</u> Annealing time 2.15 hours; Quenched from 450°C; α-phase (light) forms Widmanstätten structure in the δ (blue) background. (Pls.53,54)

<u>26 wt% Sn:</u> Annealing time 2 hours; Quenched from 725°C; β-needle banded martensite, very thin, and the same shape in 25% tin alloy. There are also large grains of β. (Pls.55-57)

<u>26 wt% Sn:</u> Annealing time 2 hours; Quenched from 650°C; Large grains of γ phase (or β_2 grains) with some cracks which might be from quenching. At the edge of the specimen there are very small amounts of features which look like β' banded martensite. (Pls.58-60)

<u>26 wt% Sn:</u> Annealing time 1.30 hours; Quenched from 550°C; There are small amounts of material similar to β' banded martensite in the middle of the large γ or β_2 gray grains. (Pl.61)

<u>27 wt% Sn:</u> Annealing time 2 hours; Quenched from 725°C; Similar to 26% quenched from 725°C, but the amount of β' banded martensite is smaller. There are large γ or β_2 grains and also subgrains inside them. (Pls.62-64)

<u>27 wt% Sn:</u> Annealing time 2 hours; Quenched from 650°C; Large grains of γ or β_2 with small subgrains or decomposition features in the grains. (Pls.65,66)

<u>27 wt% Sn:</u> Annealing time 1.30 hours; Quenched from 550°C; Large grains of γ or β_2 and a lot of small phase regions inside and along the grain boundaries. (Pls.67,68)

<u>28 wt% Sn:</u> Annealing time 2 hours; Quenched from 725°C; The large grains of γ or β_2 partially decomposed into (α+δ) eutectoid; there is also some δ in the grain boundaries. (Pls.69-71)

<u>28 wt% Sn:</u> Annealing time 2 hours; Quenched from 600°C; Similar structures to the previous sample. (Pls.72-74)

<u>30 wt% Sn:</u> Annealing time 2 hours; Quenched from 725°C; The structure may be the γ or β_2 phase with liquid trapped in some areas. (Pls.75-78)

3.3.2.3 The optical morphology of β-martensite

There are many different microphotographs of structures of quenched copper alloys in the β-phase region published by different workers. The experiment of quenching alloys of different composition and from different temperatures has been carried out in the present project. The results have been reported in detail in section 3.3.2.2.

Under the optical microscope, non-ferrous martensitic structures nearly always reveal plates which are very similar in appearance regardless of the metal or alloy in which they have been formed. As a consequence of the transformation mechanism a prepolished surface develops relief, which is a characteristic feature of martensite and can be used for recognition of martensitic transformations (American Society for Metals, 1973, 8, p.200, pl.3288).

Reeve, Bowden and Cuthbertson (1953) reported the structures of quenched high tin bronze of 14.95%, 19.90%, 24.15%, 24.90%, 25.20%, 26.60% and 28.20% (wt% tin) from high temperatures in the β-phase range. There is between 0.01-0.05 wt% of phosphorus in these alloys.

Chadwick (1939) showed micrographs of copper-tin alloys of 20 wt% tin, 0.1 wt% phosphorus, and 25 wt% tin, 0.1 wt% phosphorus, quenched from 700°C and 550°C.

Nishiyama, Shimizu and Murikawa (1968) illustrated the optical microstructures of banded martensite β' of 24.5 wt% tin quenched from 700°C in iced water (p.208, pl.1).

Kennon and Miller (1972) also published a photomicrograph showing β_1' martensite and α-phase in a 21.88 wt% Sn (13.04 at%) alloy quenched from 675°C, and a photomicrograph showing β_1' martensite in a 23.89 wt% or 14.39 at% Sn alloy quenched from 780°C. The β_1' martensites appearing in these two alloys had coarse compact needle-like structures. They also published a photomicrograph showing β_1 and banded martensite (they used β' as a symbol for banded martensite or long thin needle features separated by β_1 matrix, or the β_2 phase of this present thesis) in a 24.89 wt% Sn or 15.07 at% Sn alloy quenched from 715°C.

From these references and personal experience of the quenching experiments, there are some interesting points about martensite in Cu-Sn alloys which can be described as follows:

A. The amount of martensite increases in the range of 23% up to 24 wt% Sn in Cu-Sn alloy quenched from the high temperature region of approximately 750°C-600°C.

B. The alloys of 25 wt% Sn, 26 wt% Sn and 27 wt% Sn have less of a martensitic structure than 24 wt% Sn. The alloy of 26 wt% Sn quenched from ~720°C shows less martensites than 25 wt% Sn.

C. The 28 wt% Sn quenched from a high temperature does not show any martensitic structure.

D. The optical morphology of β-martensite.

D.1. From experiments on standard alloys. Under the optical microscope the martensite of 23 and 24 wt% tin quenched from a high temperature shows aggregates of acicular or needle-like structures. The needles seem to have different lengths: some are very long, some are very short and compact. These needles seem to appear as individual needles parallel to each other (see plates of the alloy of 23% Sn and 24% Sn quenched from 750°C). Long parallel needles of β martensite intersect in some areas. Not all long needles of β martensites are parallel to each other. The short β martensites are very compact. They are generally parallel to each other, but some have slightly different angles of orientation. Since they are short needles, the boundaries of intersecting structures do not show up (see the photographs of 23% and 24% tin bronze quenched from 750°C; Pls.23-26 and 34,25).

D.2. Under the optical microscope, the martensitic structure of 25 wt% and 26 wt% tin quenched from 750°C and 650°C shows very thin straight line markings on the large grains (these lines are called banded martensites by many authors, e.g. Nishiyama, Shimizu and Morikawa). These martensites have very thin and long parallel lines. In some areas there are intersections of straight parallel thin lines. This type of martensite is also found in a very small quantity in some areas of the alloys of 23 wt% and 24 wt% Sn together with the short compact acicular needle-like martensite.

3.3.2.4 Discussion of the similarities and the differences in conditions between the present quenching experiments on standard alloys, and the experiments by other researchers.

Similar structures to D.1 and D.2 have been found and reported in many references mentioned above, but there are some different points which should be taken into consideration as follows: The alloys used in the experiments reported in this thesis and in these references have slightly different compositions. Their alloys have been carefully prepared and homogenized for 24 hours before quenching.

The exact compositions have been analysed by independent analytical techniques. The alloys prepared for the present experiments have not been analysed. The alloys have been annealed less than is reported by certain other workers, although the time appears to have been sufficient. All of the alloys prepared for this project were quenched in water at room temperature (at around 10-20^{o}C). All alloys in the literature were quenched in ice-water or water at 0^{o}C. Some of the other researchers used the alloys of copper-tin with a very small amount of phosphorus. However, the experiments reported here are in closer imitation of the fabrication techniques used in antiquity, and should therefore be better for the interpretation of structures in ancient artifacts. In annealing the standard alloys, not all were completely homogenized in order to see the effect of this on the metallographic structure. Most of the samples prepared were very small in size, approximately 1cm x 1cm x 0.5cm. The details of the length of time for homogenization are shown in the experimental section. For most of the alloys the homogenization time was sufficient (see the microstructure of those quenched standard alloys). Only the 20 wt% Sn standard alloy was not homogenized for very long. This alloy was homogenized only 1 hour and was annealed for 2 hours before quenching in water. The metallographic structure of this particular alloy reveals large dendritic structures of α-phase of nearly perfect form, in a background of beta martensitic structure. The homogenization time is not long enough to change the dendrites to the polyhedral α-phase.

The temperature of water for quenching is not necessarily

0^oC, as Kennon and Miller (1972) had shown in their experiments. They quenched the alloys in water at 20^oC. They also reported the influence of M_s and M_f temperatures on the transformation in table 2 of their article. The complete β_1 to β_1' transformation of the martensitic structure started above 20^oC and finished at or above 20^oC for the alloy of 13.0 to 14.39 at% Sn or 21.82 to 23.89 wt% Sn (M_s = the starting temperature for martensitic transformation; M_f = the finishing temperature for martensite transformation).

3.3.2.5 Conclusions from the optical microstructures of beta martensites and the formation condition of these martensites

From previous work and the experiments undertaken for this project, conclusions can be stated as follows:

There are 4 types of beta-martensite in the copper-tin alloy system:

A. β_1'

B. β_1''

C. banded martensite. The symbol β' is used by Nishiyama, Shimizu and Morikawa (1967) and Kennon and Miller (1972). Later on the crystal structure of banded martensite β' was studied and given the symbol β_1' (Shimizu, Sakamoto and Otsuka, 1975).

D. β'' - wedged martensite.

A. β_1' and B. β_1''

Optical morphology: These 2 types of martensites β_1' and β_1'' cannot be distinguished by the optical microscope (Warlimont, 1965). The overall appearance under the optical microscope is an acicular, needle-like structure. This martensite is usually a coarse aggregate of acicular needles (Pls.23-26 and 34,35). Kennon and Miller (1972) also illustrated this type of martensite in their paper.

The composition range of the coarse β_1' and β_1'' needle-like martensites:

Since one cannot distinguish by optical microscopy between β_1' and β_1'', the composition ranges of these 2 martensites must be treated together. The lower composition limit for the β_1' transformation is at 13.0 at% or 21.85 wt% Sn at 798°C (Hanson, 1960). The range of this martensite will be in the β martensite range up to less than 24.5 wt% Sn (this figure is used by Nishiyama, Shimizu and Morikawa, 1968).

From the present experiments on standard alloys, the quenched alloys of 20%, 22%, 23% and 24 wt% Sn give the coarse needle-like structure. The alloy of 25 wt% Sn gave thin long markings on the large grains. These experiments were not performed on the alloy of 24.5 wt% Sn. The figure of 24.5 wt% Sn should be accpeted since there are many other researchers who mention the appearance of long-thin markings in the structure of the alloy of 24.5 wt% Sn.

Quenching temperature limits for β_1' have been proposed by Kennon and Miller (1972, tables 1 and 2). It was found necessary to quench the alloys of 21.85-23.89 wt% tin (13.0-14.39 at%) from above 667°C to achieve the complete transformation of the β_1' martensite (Kennon and Miller, 1972). The true composition limits for the formation of the β_1' and β_1'' martensites studied by Warlimont and Härter (1966) are 14.0 and 15.0 at% Sn (23.32 and 24.8 wt% Sn) (see also figs. 6 and 7).

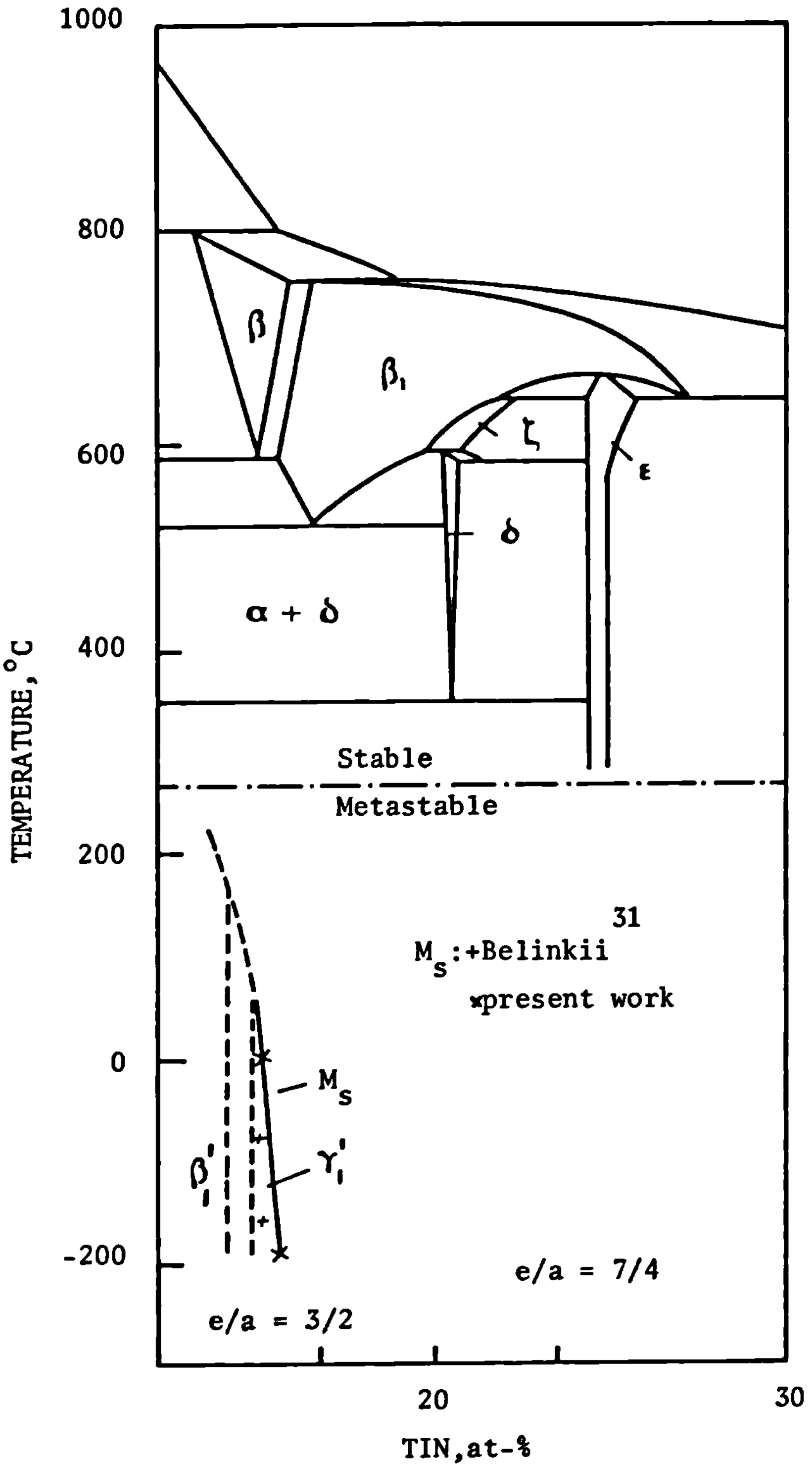


Fig. 6 Stable and metastable phases in relation to the β-phase of copper tin alloy

C. Banded martensite

Optical morphology: This martensite appears as straight long thin markings on large grains (Pls.42-44). The composition range of banded martensite extends from 24.5 wt% up to 26.6 wt% tin. These figures were derived from the following experiments:

C.1. This structure has been found in alloy of 24.5 wt% Sn quenched from high temperature (700°C) into iced water (Nishiyama, Shimizu and Morikawa, 1968).

C.2. The same structure of banded martensite has been reported in the alloy of 26.6 wt% Sn, quenched from 700°C in iced water (Reeve, Bowden and Cuthbertson, 1953).

C.3. Banded martensite was also reported by Kennon and Miller (1972). They published a photomicrograph showing β_1 and β' (banded martensite) in a 15.07 at% Sn (24.89 wt% Sn) alloy quenched from 715°C.

C.4. From experiments carried out for this project, the banded martensite was found in the alloysof 25 wt%, 26 wt%, 27 wt% quenched from around 725°C and 750°C (Pls.42-44, 55-57, 62-64).

D. Wedged martensites (β'')

This martensite has an ordered orthorhombic twinned structure (Warlimont and Härter, 1966). The optical morphology of wedged martensite: Since this type of martensite has not been found in ancient artifacts, the detailed analysis of this structure will not be discussed here. Wedge martensite has been discussed above (section 3.3.2.1).

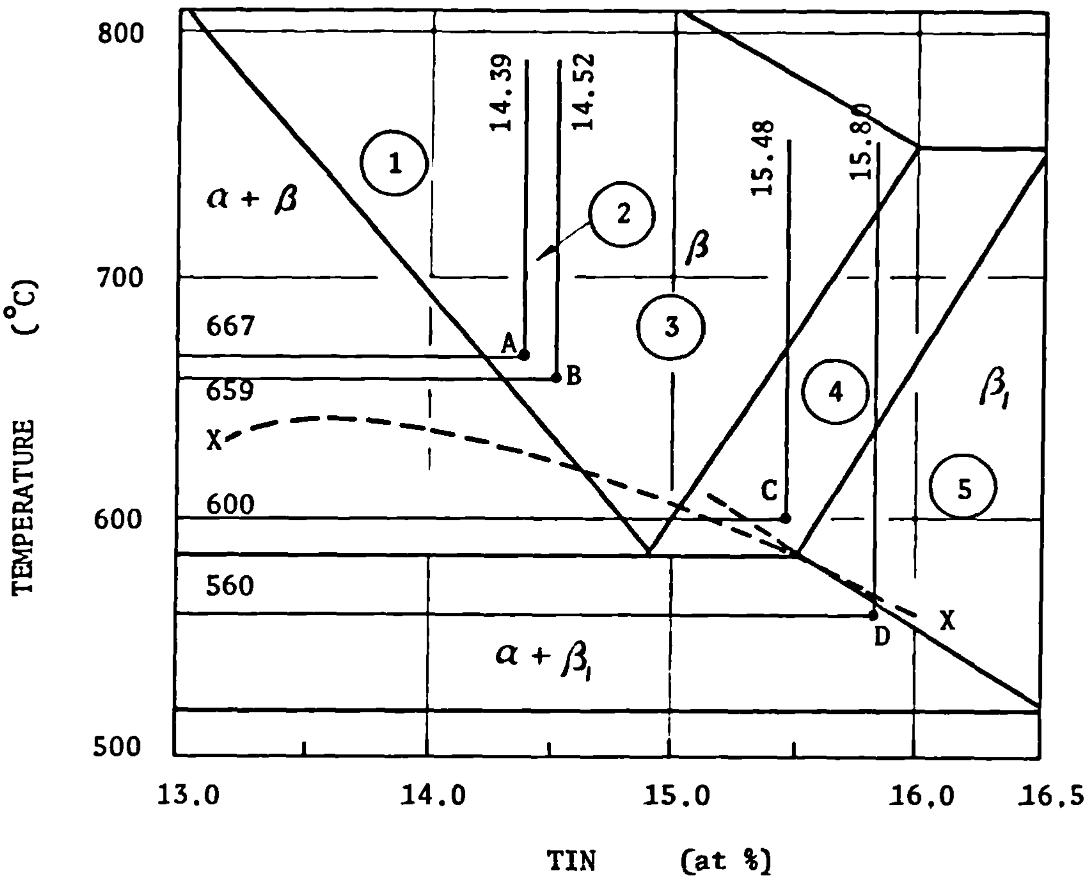


Fig. 7 Part of the Cu-Sn phase equilibrium diagram (10) showing the variation of transformation behaviour with alloy composition and quenching temperature:

(1) complete β_1 to β_1' at 20°C; (2) partial β_1 to β_1' at 20°C (3) complete β_1 to γ_1' at -196°C; (4) partial β_1 to γ_1' at -196°C; (5) β_1 untransformed at -196°C

3.4 LEADED BRONZE

Lead is found in artifacts of low-tin bronze in quite a considerable amount. For modern alloys, lead is added to improve fluidity and machinability and especially bearing characteristics. It has been used a lot in antiquity for improving the fluidity in casting. Lead is insoluble in copper-tin alloys. It is always found as globular particles in the grains of the alloy. Cuthbertson (1960) mentions that lead has been claimed to improve the soundness of bronze and gun-metal (Cu-Sn-Zn alloy) casting by filling up shrinkage and other cavities. He is doubtful whether this claim can be justified. Lead greatly increases the solidification range and can lead to severe segregation. For modern alloys, it was also found that at least 5% of lead is needed to enable these alloys to be described as bearing metal. Bearing properties improve fairly rapidly as the lead is increased from 5 to about 15%. As the amount of lead approaches 25 wt%, the bearing property slowly increases.

The microstructure of lead-bronze: The characteristic structure of lead in bronze is black globular particles. The lead globules will be distributed all over the structure.

3.5 INCLUSIONS

There are two main types of inclusion, metallic and non-metallic inclusions. The inclusions found in the artifacts from Thailand are mainly non-metallic oxide and sulphide inclusions. Under the optical microscope, it is possible to see the colour of particular inclusions and to identify some, such as cuprous oxide inclusions on this basis.

Cuprous oxide appears as grayish blue particles. Normally the inclusions are found segregated near the boundary of the grains. In cast metal, the inclusions are mainly found in the interdentritic spaces together with the $(\alpha+\delta)$-eutectoid phase. The oxide inclusions are rather soft and show plastic deformation. They are elongated perpendicular to the direction of working. The electron microprobe has been used in identifying the type of inclusions by analysis of their composition.

4. MICROSTRUCTURE FOUND IN ANCIENT COPPER ALLOY ARTIFACTS

4.1 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN THE ARTIFACTS FROM KOK KHON

4.1.1 Containers

4.1.1.1 Twinned α-phase in coarse acicular needles of β-martensite:

The object was cast and slightly hot worked. It was then heated up to the (α+β) range ($798^{o}C-586^{o}C$) and quenched.

Examples of this type of structure are found in objects no. 1006, 1009 and 1014.

4.1.1.2 Twinned α-phase in a short coarse acicular martensite, together with long-thin markings of banded martensite.

The object was cast and slightly hot worked. It was then heated up to the (α+β) range ($798^{o}C-586^{o}C$) and quenched.

An example of this type of structure is found in object no. 1018B.

4.1.1.3 Twinned α-phase in a background of long thin markings or thin needles looking like strain lines (banded martensite) in the original large β-grains:

The object was hot worked and quenched from the (α+β) range ($798^{o}C-586^{o}C$).

An example of an object which has this type of structure is object no. 1001.

4.1.1.4 Twinned α-phase in a gray background of retained β-grains (β_2):

The object was cast, hot worked and then annealed in the temperature range $520^{o}C-586^{o}C$ prior to quenching.

An example of an object which has this type of structure is object no. 1013.

4.1.2 Bracelets

4.1.2.1 Well developed α-dendrites in partially corroded (α+δ) eutectoid.

The object was cast and freely cooled without subsequent heat treatment or working.

Examples of this type of structure are found in objects no. 1004, 1011, 1016 and 1027B. In samples having a very low tin content, some polishing marks were visible due to the softness of the alloy (see object no. 1023).

4.1.2.2 Cored α-dendrites in partially corroded (α+δ) eutectoid.

The object was cast and fairly rapidly cooled.

An example of this type of structure is found in object no. 1020A.

4.1.2.3 α-dendrites with very small interdentritic areas (nearly pure single phase alloy). The size of the α-dendrites is large but there is coring in some areas.

The object was cast and slowly cooled. The tin content must be low as the area of interdendritic structure is very small.

An example of this type of structure is seen in object no. 1010.

4.1.2.4 Cored α-dendrites with a very small area of interdendritic structure (not very easily seen).

The object was cast and rapidly cooled, the tin content of the alloy must be low.

Examples of this type of structure are seen in objects no. 1031 and 1034.

4.1.2.5 Polygonal α-phase grains with very small areas of (α+δ) eutectoid.

The object was cast; the tin content of the alloy must be low.

An example of this type of structure is seen in object no. 1026.

4.1.2.6 Twinned α-phase grains in a matrix of β-martensite.

The object was cast, slightly hot worked, and heated up to the (α+β) range (798°C-586°C) before quenching.

An example of an object having this type of structure is object no. 1017.

4.1.2.7 α-phase with a lot of gas cavities and lead globules, and uncorroded eutectoid in some areas.

The object was cast. Lead globules are distributed throughout the specimen. In some areas one can see traces of dendrites although they are not clear.

An example of an object having this type of structure is object no. 1029.

4.1.3 Rings

Dendritic structure with partially corroded eutectoid.

Metallographic examination revealed an as-cast structure. The sample was soft and showed polishing marks.

An example of this structure is seen in object no. 1008.

4.1.4 Arrowhead

Cored α-dendrites in a well developed form with a small area of eutectoid.

The object was cast and freely cooled without any subsequent heat treatment.

Object no. 1005 exemplifies this structure. The sample was taken from near the tip, and there is no evidence of hot or cold working.

4.1.5 Socketed axe

α-dendrites with eutectoid in the interdendritic spaces.

This object was cast and slowly cooled without any heat treatment or working.

This structure appears in object no. 1028.

4.1.6 Coil of thin wire

Twinned rounded α-phase in eutectoid background.

Probably cast as a rod, worked extensively, and annealed for a long time at a high temperature. The α-phase is small and rounded in shape. From the longitudinal section, there is no evidence of drawing. The section was square.

An example of an object having this structure is object no. 1007.

4.1.7 Helically wound strip

Twinned round α-phase in a background of acicular coarse needles of β-phase.

The microstructure indicates that the wire was cast, slightly worked in the hot state, and annealed to the (α+β) temperature range ($798^{o}C$-$586^{o}C$) before quenching.

Examples of fragments from Khok Khon which have this structure are objects no. 1018A, 1019, 1020B, 1024 and 1025.

4.1.8 Cast "false wire" helix

Polygonal grains with segreation of the impurities along the grain boundaries.

From the structure, this object was cast and annealed. The tin content was very low; the object was rather soft. Polishing marks could be seen in some places.

An example of this type of structure can be seen in object no. 1022.

4.2 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN THE ARTIFACTS FROM NON CHAI

4.2.1 Bracelets

4.2.1.1 α-dendrites in corroded eutectoid with some lead globules. The area of eutectoid is reasonably large, indicating a fairly high tin content in the alloy. There are some black lead globules distributed in the sample.

From the structure it may be deduced that the object was cast and slowly cooled.

This type of structure is seen in object no. 1101.

4.2.1.2 α-dendrites in a well-developed form with a little interdendritic eutectoid and some black dots (probably lead globules).

The object was cast and slowly cooled. The amount of tin in the alloy was low.

Examples of this type of structure are seen in objects no. 1128, 1129A, 1130, 1135B, 1136A, 1136B, 1145A and 1145B.

4.2.1.3 α-dendrites in a well-developed form with a very small amount of eutectoid and no lead globules.

The object was cast and slowly cooled. The proportion of tin in the alloy is very probably low.

An example of this type of structure is object no. 1104.

4.2.1.4 Structure of twinned α-phase forming a pattern similar to the Widmanstätten structure. Some of the α-phase is rounded, and some is in an elongated form, on a background of β-phase.

The interpretation of this type of structure is that the object was cast, then heated up to the (α+β) region and worked, then annealed at a temperature above $520^{\circ}C$ (between 520°-$586^{\circ}C$) and quenched in water.

An example of an object which has this type of structure of object no. 1105.

4.2.1.5 Small α-dendrites in a background of eutectoid. There is no sign of coring in the α-phase.

This object was cast and cooled at a reasonable rate.

An example of this type of structure is object no. 1106.

4.2.1.6 Structure of cored α-dendrites with a very small area of interdendritic structure. There are also some lead particles in the structure. The object was cast and rapidly cooled, and the content of tin in the alloy must be low.

Examples of objects with this type of structure are objects no. 1109, 1111, 1115, 1120, 1121B, 1123, 1124, 1125, 1127, 1129B, 1129C, 1131A, 1131B and 1135A.

4.2.1.7 There is one sample with very extensive corrosion There is no clear evidence of dendrites. The structure looks like polygonal grains, but there are some features looking like eutectoid in the interdendritic area.

From the structure, this object may be cast and annealed.

The example is object no. 1102.

4.2.1.8 The structure revealed the α-phase with very large gas porosities and shrinkage voids. There is no sign of α-dendrites. The α-phase appeared white, and the gas porosities or casting cavities appeared as black dots. There are some small lead globules in some areas.

The object was cast and annealed. There was no evidence of working.

This type of structure was found in object no. 1137.

4.2.1.9 Structure of twinned α-phase on a background of β-martensite. The β-needles seem to fill the original β-grain. The amount of α-phase was very small, and the α-phase regions were also small and rounded.

This object must have been cast, heated up to the (α+β) region, and worked. Then the object was heated up to above 586°C (in α+β region) and quenched in water. There was also evidence of elongated cuprite inclusions lying perpendicular to the direction of working.

The object having this type of structure was object no. 1118.

4.2.2 Bracelet with bell

The structure is one of cored α-dendrites in a eutectoid. The size of the dendrites is large. The dendrites are in the eutectoid background with some cast cavities and black lead particles.

The object must have been cast and air cooled.

The object with this type of structure was object no. 1116.

4.2.3 Bell

The structure is of α-dendrites in a background of eutectoid. There are some black lead particles.

The object was cast.

Examples of this type of structure are objects no. 1117, 1138, 1139 and 1140.

4.2.4 Large bell

The structure is of α-dendrites, with very small areas of eutectoid. In some areas the meeting place of each dendrite gives very clear boundaries.

This object was cast, and has a low tin content.

The examples of objects with this type of structure are objects no. 1142A, 1142B and 1143.

4.2.5 Fragment of bronze vessel or large bell

The structure is of α-dendrites in (α+δ) eutectoid. The amount of (α+δ) eutectoid is rather small.

The object was cast.

The object with this type of structure was no. 1132.

4.2.6 Rings

4.2.6.1 The structure consisted of cored α-dendrites in (α+δ) eutectoid. The amount of (α+δ) eutectoid is rather low.

The object was cast.

Examples of this type of structure are found in objects no. 1107, 1108 and 1110.

4.2.6.2 The structure is of β-martensite (very compact and short and fine). There are very small areas of α-phase scattered all over on a background of β-martensite.

The object was cast, then heated up to the (α+β) region ($798^{\circ}C$-$586^{\circ}C$) and then quenched into water.

This type of structure is found in object no. 1119.

4.2.7 Ornament

The structure is of cored α-dendrites in a very small area of (α+δ) eutectoid (hardly seen under an optical microscope). The α-dendrites are of a rather small size.

The object must have been cast and rapidly cooled.

This type of structure is found in object no. 1112.

4.3 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN ARTIFACTS FROM MISCELLANEOUS PLACES IN NORTH EAST THAILAND

4.3.1 Bracelets

4.3.1.1 The cored dendritic structure consisted of α-phase in (α+δ) eutectoid with lead globules distributed all over the sample.

The object was cast.

Examples of objects with this type of structure are objects no. 1901F, 1905C, 1911 and 1912A.

4.3.1.2 Dendritic structure of α-phase in (α+δ) eutectoid. The dendrites seem to be well developed. There are black globules distributed all over the sample. The amount of lead varies between objects.

The objects were cast and slowly cooled.

Examples of objects with this type of structure are objects no. 1906A, 1906B, 1909, 1912B, 1912C, 1912E and 1912F.

4.3.1.3 Dendritic structure of α-phase in (α+δ) eutectoid. The amount of (α+δ) eutectoid was very small and hardly seen under the optical microscope. There are some lead globules appearing as black dots.

The object was cast and slowly cooled.

The object with this type of structure is object no. 1913B.

4.3.1.4 Structure of β'-martensite (banded martensite or features of long thin markings) in the large grains of β-phase. This object should have a composition around 24%-25% tin and it should be cast and heated up to the β-region of around $700^{o}C$ and quenched in water.

The object found with this type of structure is no. 1904A.

4.3.1.5 Structure of twinned α-phase on a background of acicular coarse compact β-martensite.

The object has been cast, and slightly hot-worked. It was then heated up to the (α+β) region (798^{o}-$586^{o}C$) and quenched in water.

The objects found with this type of structure were objects no. 1904B and 1905B.

4.3.1.6 α-phase structure with heavy strain lines in an unidentified background (due to corrosion).

The object seems to be cast and annealed then cold worked. Another explanation may be that the object was cast then hot worked extensively, then quenched from the (α+β) region at around 798^{o}-$586^{o}C$ into water. The β-martensite in the background corroded away completely.

The object found with this type of structure was object no. 1913A.

4.3.1.7 The structure consisted of very small α-phase regions (some are twinned α-phase) on a background of very compact needles of β-martensite.

The object must be cast and heat-treated and the content of tin should be in the nearly pure β-phase or nearly 23% tin (the amount of α-phase was very small) and the object was hot worked and quenched from around 700°C into water.

The example found was object no. 1904C.

4.3.2 Bead

The structure consisted of cored dendrites in a background of eutectoid with black lead globules.

The object was cast and not otherwise treated.

This type of structure is found in object no. 1902A.

4.3.3 Axe

From the cutting edge, the structure revealed equi-axial grains with bent twin bands and heavy strain lines.

This suggested that the axe was cast then cold worked, annealed, and then cold worked again. The heavy strain lines and bent twin bands are evidence of cold working at the final stage of manufacture of the cutting edge. Another cause of such strain lines may be due to the stress from the cutting action when the axe was used.

This type of structure was found in object no. 1905A (cutting edge sample).

From the side of the axe, the structure revealed the structure of cast low-tin bronze. There was no evidence of dendrites. In a small area there were twin bands in equi-axial grains.

The interpretation of the structure of the sample can be described as that the object was cast and slightly worked and then annealed.

This type of structure was found in object no. 1905A (from the side of the axe).

The overall technology of the axe (1905A) was firstly casting into shape. The cutting edge was then hammered down for the process of sharpening, then the axe was annealed but only the cutting edge was hammered down again (the bent twin bands and heavy strain lines).

4.3.4 Kettle-drum

The structure consisted of α-dendrites in a nearly completely corroded (α+δ) eutectoid. There were also a lot of casting cavities and lead globules throughout the specimen.

The object was cast.

Examples of this type of structure are found in objects no. 1915A and 1915B.

4.4 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN THE ARTIFACTS FROM NON NOK THA

4.4.1 Bracelet

4.4.1.1 The structure consisted of cored α-dendrites in a background of eutectoid. The dendrites are in a well developed form. The dendrites in various objects were small or large. There are no large shrinkage or casting cavities. The amount of lead is rather lower than 1 wt%. There are few lead globules in the sample.

The object must be cast, and fairly rapidly cooled.

This type of structure is found in objects no. 15053 and 15074 (large dendrites); 15066 (small dendrites).

4.4.1.2 The structure consisted of α-dendrites in the eutectoid. The dendrites are in a well developed form, and the size of dendrites is large. The amount of lead is less than 1 wt%, and the lead globules do not appear very clearly.

The object was cast and slow cooled.

Examples of this type of structure are found in objects no. 15013, 15077.

4.4.1.3 The structure consisted of cored α-dendrites in $(\alpha+\delta)$ eutectoid. There are large casting cavities and large amounts of small black lead globules. The amount of lead in this type of structure is higher, above 1 wt% lead.

The object was cast, and fairly rapidly cooled.

Examples of this type of structure are found in objects no. 15017, 15023, 15052, 15054, 15057, 15058, 15059, 15062A, 15062B, 15063 and 15079.

4.4.1.4 One object has a combination of many phases. The overall structure is dendritic, but it was heavily corroded, especially on the edge. In the middle part there are some areas having an unusual appearance of needle-like structures in a polygonal grain.

The object has been cast, annealed in the $(\alpha+\beta)$ region for a short time, and quenched before equilibrium has been achieved.

This structure is found in object number 15039.

4.4.2 Rings

4.4.2.1 The structure consisted of cored dendrites on a background of $(\alpha+\delta)$ eutectoid with a reasonable number of lead globules.

The object was cast.

This type of structure is found in object number 15051.

<u>4.4.2.2</u> The structure consists of twinned α-phase. This sample is a longitudinal section. The structure revealed twinned α-phases and elongated cuprite inclusions. These inclusions are elongated and arranged perpendicular to the direction of working.

The object was cast, then worked and annealed.

This type of structure is found in object number 15071.

4.4.3 Fragment of blade

The structure consisted of equiaxial grains with twin bands. In some areas there are still traces of dendrites and eutectoid in the interdendritic area.

The object was cast, then worked, and annealed for not quite long enough to remove the dendritic structure.

This structure is found in object no. 15022.

4.4.4 Fragments of bronze

The copper-rich α-phase only appears. There is no clear evidence of dendritic structure. The object was rather low in tin content.

It was cast and annealed. There is no other evidence of working.

This type of structure is found in objects no. 15021, 150116.

4.4.5 Metal droplets

The structure consisted of cored α-dendrites in (α+δ) eutectoid. It was obviously a cast structure from the microstructure.

This droplet was spillage from the molten metal used in casting.

Examples of this type of structure are found in objects no. 15100 and 15102.

4.5 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN THE ARTIFACTS FROM BAN NA DI

4.5.1 Cutting tools

The structure consisted of equiaxial grains, with a lot of corrosion product.

The object was cast then annealed; the edge may have been worked.

The example was object no. 16001. This object was corroded very badly. The structure of equiaxial grain is the only remaining feature.

4.5.2 Bracelets

4.5.2.1 The structure revealed a large grain of β_2 phase (β_1 or γ phase in some texts) with α+δ eutectoid inside the grain, the α-phase forming along the original β grain boundaries. The leaf-like phase is α-phase. The α-phase seems to form a Widmanstätten pattern in the β-grains. The decomposition of β-grains into (α+δ) eutectoid is only partial. The very dark dots are iron inclusions; before etching these appear as silvery metallic inclusions. From the analytical results, the composition of tin in this sample was 29 wt% tin.

The object was cast and quenched from the β_2 region (β_1-ordered region or γ region) at around 600°C into water.

This type of structure is found in object no. 16064.

4.5.2.2 The structure consisted of twinned α-phase in (α+δ) eutectoid, the α-phase is small.

The object was cast, then worked and annealed.

This type of structure is found in object no. 16069.

4.5.3 Ring

The structure consisted of cored dendrites with very little $\alpha+\delta$ eutectoid. There are few black lead globules.

The object was cast.

This type of structure is found in object no.16058.

4.5.4 Pendant

The structure consisted of cored dendrites in $(\alpha+\delta)$ eutectoid. The eutectoid was present in a small amount due to the low content of tin in the alloy. There are also small black lead globules.

The object was cast.

This type of structure is found in object no. 16002.

4.5.5.1 The structure consisted of cored α-dendrites with a small amount of $(\alpha+\delta)$ eutectoid in the interdendritic space.

The object was cast.

The example was object no. 16004.

4.5.5.2 The object was very badly corroded. The structure is α-phase in the corroded unidentified background. In some areas the corroded background showed features of β-martensite.

This object was probably cast and quenched from the $(\alpha+\beta)$ region (586°-$798^{\circ}C$) into water.

The example was object no. 16029.

4.5.5.3 The object was completely corroded. There are some traces of twinned α-phase in the corroded unidentified background.

The example was object no. 16043.

4.6 SUMMARY OF THE TYPES OF STRUCTURE FOUND IN OBJECTS FROM BAN DON TA PHET

4.6.1 Containers and Lids, including Ladles

4.6.1.1.1 Structures with α-phase in a needle-like matrix of β-phase.

The object was cast, then hot worked before annealing in the (α+β) phase region and then quenched from that temperature (798°-586°C). Among these types of structures from the samples from Ban Don Ta Phet, three slightly different structures can be identified:

4.6.1.1.2 Small twinned α-phase in needle structure of β-phase matrix.

This structure might result from the object being cast, slightly worked in the hot state, annealed to the temperature of (α+β) range (798°-586°C) and quenched. According to the equilibrium diagram, this type of structure should be the quenched structure of an alloy of high tin content of at least 20% tin, since the amount of the α-phase is very small compared with the needle-like structure of the β-phase. The percentage of tin should not be over 24.6 or 25% since at this point the structure should be only pure needles of β-phase (or with very small amounts and size of α-phase).

Examples of the samples of Ban Don Ta Phet which have this structure are:

P 17	fragment of bronze	
P 31	body of container	lab.no. 18006B
P 31	rim of container	lab.no. 18006A
P 43	lid of container	
P 48	container	

For lab no. 18019, P 43, there are some interesting points to mention besides the structure of small twinned α-phase in very fine needles of β-phase. Although the object seems to be very heavily corroded, the only sound metal in this object was at the surface suggesting inverse segregation or uneven quenching.

The quantitative analysis of the sample lab.no.18020, P 48, is Sn 29.55%, Cu 70.45% which does not agree with the theoretical prediction. The explanation may be that sample was corroded, the copper leaching out and the error from the measurement caused by the machine.

4.6.1.1.3 Twinned α-phase in needle structure of β-phase with some features similar to strain lines, which has been explained as banded martensite.

The object was cast, hot worked quite a considerable amount, then annealed in the (α+β) region (798°-586°C), and quenched.

According to the equilibrium diagram, this type of structure should be the quenched structure of alloys of high tin bronze of about 20% tin ±2% since the amount of α-phase is quite reasonably high compared with the β-phase (compare the structure of type 4.6.1.1.1). The content of tin should not approach 25% since the structure of the samples does not correspond to the structure of 25% tin bronze with only the needle-like β-phase.

The features which are similar to strain lines in the samples may occur because of the strain from quenching (Reeve, Bowden and Cuthbertson, 1953). It has been suggested that these lines are banded martensite due to the martensitic transformation in the particular high-tin bronze quenched from (α+β) range,as noted in section 3.3.2.5.

The examples of the samples from Ban Don Ta Phet which have structures corresponding to this type are:

P33(B)	lid
P69	container

The quantitative analysis of object P69 is Sn 31.5% Cu 68.5%. This content of tin is too high and does not seem to correspond to the structure and the theoretical explanation. The results may not be accurate because the object analysed was corroded.

4.6.1.1.4 Structure related to type 4.6.1.1.1.

Small, twinned, partly rounded α-phase in needle-like matrix of β-phase, and some features similar to strain lines or long markings on the big grains. An example is lab. no. 18016A, P29, spoon part.

The object was cast, then hot worked and annealed and quenched from the (α+β) region (798^{o}-580^{o}C). The explanation is the same as type 4.6.1.1.1 and the only difference is that the α-phase seems to be rounded and there are some features similar to strain lines which is now identified as banded martensite in the structure which is the effect of heat treatment. The rounded α-phase is probably due to the rather longer annealing time.

4.6.1.2 Structure with dendrites and a needle-like structure of β-phase in between.

The explanation of the manufacture of the object is that it was cast, briefly annealed and quenched. The quenching temperature should be in the range of 798^{o}-586^{o}C.

Examples of the samples from Ban Don Ta Phet which have this structure are:

P18 (2)	
P30	lab.no. 18008

For P 18 (2), the needle-like structure of β-phase appears in a small amount. The reason may be that the amount of tin in this sample was not very high.

In lab.no. 18008, P 30, the dendrites were large and the amount of β-phase was quite high. The composition of tin in this sample is Sn 31.8%, Cu 68.2%. This sample must be in the as-cast state and was quenched very rapidly. The percentage of tin from the analysis did not correspond with the structure of the sample. It may be the result of corrosion in the sample.

4.6.1.3 The needle-like structure of β-phase only.

The object was cast, then annealed and quenched from the β-phase region (755°-586°C). From the equilibrium diagram, the composition of tin in this type of alloy should be about 25%.

Examples of the samples from Ban Don Ta Phet which have corresponding structures to this structure are:

P 24 lab.no. 18014
P 34

4.6.1.4 The structure of twinned α-phase in a matrix of (α+δ) eutectoid.

This structure shows evidence of casting, then hot working and annealing in the temperature range of (α+δ) phase (520°-350°C). An example of this type of structure is LM 127.

4.6.1.5 Structure of twinned α-phase with small areas of β-phase, heavy strain lines or long thin markings in certain areas.

The object was cast, then heavily hot worked (as shown from the twin bands) and quenched (as shown from the needle structure in some areas) from a temperature of about 700°C.

Examples of the samples from Ban Don Ta Phet which have this structure are:

P 7	thick container	lab.no. 18012
no.9 (13)	thick container	
rim 530/2519	thick container	lab.no. 18022A
rim 530/2519	thick container	lab.no. 18022B

The appearance of a lot of strain lines in the structure was explained in two papers. Reeve, Bowden and Cuthbertson (1953) showed the structure of a 26.6% tin bronze which was annealed at 700°C for 24 hours and quenched in iced water. It shows a lot of parallel strain lines in different directions in the large grain background which corresponds to the structures of the above samples. Chatterjee and Hoare (1965) give an example of the microstructure of a 23.3% tin bronze annealed at 700°C and quenched. This microstructure shows a lot of parallel strain lines of β'-martensite in different directions in the large grain background of β-grains. Chatterjeee and Hoare called the strain lines in this structure β'-martensite and identified the large grains as β-grains. It is now clear that those long markings were β' banded martensite. The details of how these types of martensite occur have been discussed in section 3.3.2.5.

4.6.1.6 Special structures.

The structure of P 61, container, is the twinned α-phase and non-twinned plates of α-phase in a gray background of a β_2 phase (Border phase, β_1 or γ phase in some texts). The interpretation of the structure was not fully understood.

The object was cast and hot worked, then heated up to the ($\alpha+\beta_1$) region (see equilibrium diagram, fig.7).

The structure of lab.no. 18021A, P 61, rim,is that of islands of α-phase in a matrix exhibiting strain and acicular precipitation, possibly an unidentified high temperature phase. The interpretation of the structure is not certain.

The explanation of the structures of P 18 (4) and P 3 is not certain.

The structure of P 29, ladle handle,showed small round islands of twinned α-phase in an unresolved background with numerous strain lines which now are explained as banded martensite (β' martensite). It was cast and hot worked, then annealed and quenched from the ($\alpha+\beta_1$) region. It is very interesting to compare this structure to the ladle which was cast, annealed and quenched. The handle may not have been treated in the same way, but it should have been cast in one piece together with the ladle bowl.

4.6.2 Bracelets

The structures can be divided into three main types:

4.6.2.1 Dendritic structures with ($\alpha+\delta$) eutectoid which is partially corroded.

This type of object was cast and freely cooled without any heat treatment or working. Examples of samples from Ban Don Ta Phet which have this structure are:

P 18 (1)	
P 25	lab.no. 18015
P 38	lab.no. 18018
P 53	
P 65	

The composition of these bracelets usually includes lead in a quite considerable amount.

4.6.2.2.1 Equiaxial structure of α-phase and (α+δ) eutectoid.

This structure is the result of casting and annealing for a long time, enough to change the dendritic structure of α-phase into equiaxial grains. An example of the samples from Ban Don Ta Phet which have a corresponding structure is P 16.

4.6.2.2.2 The round twinned α-phase.

This structure is the result of casting, working and then annealing for a short time. An example is shown in P 18 (5).

4.6.2.3 The structure with very small α-phase in a matrix of β-phase.

The object was cast, then annealed to the temperature of (α+β) range (798^{o}-586^{o}C) and quenched. An example of the samples from Ban Don Ta Phet which have corresponding structures to this type of structure is P 44.

4.6.3 Rings

There are two types of structure:

4.6.3.1 Dendritic structure with partially corroded matrix of (α+δ) eutectoid, with lead globules.

This type of structure shows that the object is cast and slowly cooled. The examples are lab.no. 18002, P 18 (6A) and P 18 (6C).

4.6.3.2 Fine needles of β-phase with very small α-phase regions distributed in the needle area.

This type of structure shows that the object was cast and annealed, probably between 750^{o}-586^{o}C (β-phase range) and then quenched. The composition should be very nearly 25%

tin according to the equilibrium diagram. An example is lab.no. 18010, P 18 (6B).

<u>NOTE</u>: For these objects from Ban Don Tha Phet, all the metallographic structures are presented in the previous project (Rajpitak, 1979). Only some metallographic structures are presented in this thesis. These are:

Lab.no. 18001, 2099 or 2097
Lab.no. 18002, 1097
Lab.no. 18003, 886
Lab.no. 18004, /3490 (79) bell with good patina
Lab.no. 18005, /3490 (79) bell
Lab.no. 18006A, P31 rim
Lab.no. 18006B, P31 body
Lab.no. 18007, P5 or P6 rim
Lab.no. 18008, P30 rim/body
Lab.no. 18009, P18 box 6 Ring A
Lab.no. 18010, P18 box 6 Ring B
Lab.no. 18011A bucket (handle)
Lab.no. 18011B bucket (base)
Lab.no. 18012, P7
Lab.no. 18013, P18 box 2 rim
Lab.no. 18014, P24
Lab.no. 18015, P25
Lab.no. 18016A, P29 spoon
Lab.no. 18016B, P29 handle
Lab.no. 18017, P33 rim
Lab.no. 18018, P38
Lab.no. 18019, P43 lid
Lab.no. 18020, P48
Lab.no. 18021A, P61 rim
Lab.no. 18022A, 530/215 circular decoration
Lab.no. 18022B, 530/215 line decoration

5. CATALOGUE

Abbreviations used in the catalogue:

NEAP, KK	=	North-East Archaeological Project, Khon Kaen
AD/B	=	Archaeological Division, Bangkok
IOA/L	=	Institute of Archaeology, London
HU/USA	=	Hawaii University, USA
MP	=	Middle Period
( )	=	○

Site 1. KOK KHON

(Sakon Nakhon Province; Lat. $17^{o}38'18"$; Long. $103^{o}26'11"$)

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer: (2)

Depth: 27 cm

LAB NO: 1001

EXCAVATION NO: 95

MUSEUM NO:

Plate Nos: 79-88

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a bronze vessel.

DIMENSIONS AND WEIGHT:

Width: 3 cm
Length: 7 cm
Thickness: <0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Twinned α-phase on a background of long thin needles looking like strain lines (β' banded martensite) in the original large β-grains.

COMMENTS:

The object was cast then hot worked and quenched from the (α+β) range (798^{o}-586^{o}C). The content of tin in this sample should be 23-24 wt%. A similar structure to that of this object was found in 23.19 wt% tin quenched from 654^{o}C(Kennon and Miller, 1972).

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer: (2)

Depth: 100 cm

LAB NO: 1004

EXCAVATION NO: KK 232

MUSEUM NO:

Plate Nos: 89-92

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of circular section bracelet.

DIMENSIONS AND WEIGHT:

Diameter of section: 3 mm; length: 2.7 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 96-99%; Sn 3.2-4.7%; Pb <0.01%; S, As, Fe, Sb, Ag, Au (trace)
Metallic Inclusion, Cu (Sn absent), cuprite rim

METALLOGRAPHIC STRUCTURE:

As cast structure of α-dendrites in partly corroded eutectoid. Metallic inclusions appeared in some areas, these were of pure copper and indicate incomplete homogenization of alloy.

COMMENTS:

There is twinning in the metallic inclusion; it is not redeposited copper, but a spherical droplet which escaped alloying and experienced stress during the fabrication process.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1005

EXCAVATION NO: KK 179

MUSEUM NO:

Plate Nos: 93-99

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Arrow-head with some metal core, thick layer of corrosion products.

DIMENSIONS AND WEIGHT:

Length: 3 cm
Width: 2 cm
Thickness: 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA:	Cu 90.58-97.45%	Sn 2.201-8.453%	Pb 0.04-0.08%
	S 0.009-0.09%	As 0.002-0.16%	Fe 0.076-0.129%
	Sb 0.028-0.226%	Ni 0.007%	Ag 0.033-0.187%
	Au 0.047-0.205%		
AA:	Cu 87.598%		
ICP:	Cu 105.879%	Sn 3.933%	Pb 0.114%
	As 0.098%	Sb 0.128%	Fe 0.016%
	Ag 0.053%	Ni 0.012%	Co 0.005%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites of well developed form with a small area of eutectoid.

COMMENTS:

The object was cast and freely cooled without any subsequent heat treatment. The sample was taken from near the tip, and there is no evidence of hot or cold working.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth: 75

LAB NO: 1006

EXCAVATION NO: KK 260

MUSEUM NO:

Plate Nos: 100-103

PERIOD:

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a bronze object, probably a vessel.

DIMENSIONS AND WEIGHT:

Approx. 1.6 x 1.2 cm; thickness ~1 mm.

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: α-phase; Cu 80.38%; Sn 14.893%
β-phase; Cu 73.28-74.49%; Sn 20.63-21.14%

AA: Cu 71.17%

ICP: Cu 76.788% Sn 22.528%; Pb 0.139%; As 0.163%; Sb 0.259%; Fe 0.085%; Ag 0.202%; Ni 0.037%; Co 0.007%; Bi 0.049%; Total 100.257%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in coarse acicular needles of β-martensite.

COMMENTS:

The object was cast and slightly hot worked. It was then heated up to the (α+β) range and quenched from about $700^{\circ}C$.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth: 91 cm

LAB NO: 1007

EXCAVATION NO: KK 196, 9/73

MUSEUM NO:

Plate Nos: 104-113

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Coil of thin wire, rectangular section, very corroded.

DIMENSIONS AND WEIGHT:

Diameter (coil): about 3 cm
Section: 0.7 x 0.5 mm. ▯

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Twinned rounded α-phase in (α+δ) eutectoid background.

COMMENTS:

Probably cast as a rod, worked extensively, and annealed for a long time at a high temperature (the α-phase is small and rounded in shape). From the longitudinal section, there is no evidence of drawing.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1008

EXCAVATION NO: KK 210/832

MUSEUM NO:

Plate Nos: 114-117

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Wire, circular section, bent round but not joined.

DIMENSIONS AND WEIGHT:

Diameter (ring): 1.9 cm
Diameter (section): 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP:	Cu 91.848%	Sn 2.25 %	Pb 0.812%	As 0.177%
	Sb 0.155%	Fe 0.021%	Ag 0.069%	Ni 0.027%
	Co 0.006%	Bi 0.018%		

METALLOGRAPHIC STRUCTURE:

Dendritic structure with partially corroded eutectoid.

COMMENTS:

The object was cast. The sample was soft and showed polishing marks.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1009

EXCAVATION NO: KK 95

MUSEUM NO:

Plate Nos: 118-123

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A very thin fragment of a bronze vessel with polishing marks on the surface.

DIMENSIONS AND WEIGHT:

thickness: 0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: β-phase: Cu 78.03-78.16%; Sn 23.35-23.50%; Fe 0.376% As 0.119%; Sb 0.113%
α-phase: Cu 86.16-86.42%; Sn 14.75-14.92%; As 0.130-0.266% Fe 0.302-0.398%; Sb 0.312-0.477%

ICP: Cu 74.943%; Sn 21.73%; Pb 0.174%; As 0.256%; Sb 0.181%; Fe 0.197%; Ag 0.065%; Ni 0.028%; Co 0.006%; Bi 0.016%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in coarse acicular needles of β-martensite.

COMMENTS:

The object was cast and slightly hot worked. It was then heated up to the (α+β) range, about 700°C, and quenched in water. Traces of grinding marks are visible on the surface. (See also photograph of 1001.)

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

LAB NO: 1010**

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 124-129

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragments of bracelet with decoration of bosses, etc.

DIMENSIONS AND WEIGHT:

breadth: 1.5 cm; thickness (section) 1.5 mm 

COMPOSITION: (XRF; EPMA; AA; ICP)

AA:	Cu 66.194			
ICP:	Cu 86.625%	Sn 4.106%	Pb 0.449%	As 0.079%
	Sb 0.107%	Fe 0.050%	Ag 0.046%	Ni 0.017%
	Co 0.003%	Total: 91.491%		

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in partly corroded eutectoid, with casting cavities. Gray-blue inclusions are probably sulphides.

COMMENTS:

The object was cast without further working or heat treatment. The lost wax casting technique was used, producing a thin casting to conserve metal.

CATALOGUE ENTRY

SITE: KOK KHCN

AREA: Pit:

Layer:

Depth: 92 cm

LAB NO: 1011**

EXCAVATION NO: KK 273/832

MUSEUM NO:

Plate Nos: 130-132

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Divsiion, Bangkok

EXCAVATION REF:

DESCRIPTION: 2 fragments of circular section bracelet.

DIMENSIONS AND WEIGHT:

dimension of section: 4 mm; length: 2.2, 3.2 cm 

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.577%; Sn 8.72 %; Pb 0.137%; As 0.104%
Sb 0.134%; Fe 0.123%; Ag 0.036%; Ni 0.014%
Co 0.005%; Bi 0.019%
Total 92.869%

METALLOGRAPHIC STRUCTURE:

α-dendrites in corroded eutectoid.

COMMENTS:

The object was cast without subsequent heat treatment or working, using the los wax process. The casting is solid.

CATALOGUE ENTRY

SITE:	KOK KHON	AREA:	Pit:
LAB NO:	1012**		Layer:
EXCAVATION NO:	102		Depth: 50 cm
MUSEUM NO:		Plate Nos:	133-134
PERIOD:	Iron Age	Fig Nos:	
PRESENT LOCATION:	AD/B		
EXCAVATION REF:			
DESCRIPTION:	A spoon or ladle, completely corroded.		

DIMENSIONS AND WEIGHT:

length: approx. 18 cm.

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.620% Sn 10.344% Pb 0.189% As 0.112%
Sb 0.034% Fe 0.034%
TOTAL 103.333%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1013*

EXCAVATION NO: 201/944

MUSEUM NO:

Plate Nos: 135-141

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a bronze vessel.

DIMENSIONS AND WEIGHT:

approx. 4 x 1.6 cm
thickness 1-1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP:	Cu 71.616%	Sn 29.314%	As 0.048%	Sb 0.031%
	Fe 0.246%	Ag 0.202%	Ni 0.012%	Bi 0.017%
	TOTAL 101.485%			

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in a gray background of retained β-grains (β_2).

COMMENTS:

The object was cast, hot worked, and then annealed in the temperature range 520°-586°C prior to quenching.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1014**

EXCAVATION NO: 278/944

MUSEUM NO:

Plate Nos: 142-146

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragments of bronze vessel, heavily corroded.

DIMENSIONS AND WEIGHT:

thickness: 0.6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in a short coarse acicular martensite.

COMMENTS:

The object was cast and slightly hot worked. It was then heated up to the (α+β) range (798°-586°C) and quenched. From the structure, the tin content should be about 22-23 wt% and the quenching temperature about 700°C.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1015**

EXCAVATION NO: 73

MUSEUM NO:

Plate Nos:

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment from a container, very heavily corroded.

DIMENSIONS AND WEIGHT:

thickness: 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 67.211% Sn 2.982% Sb 0.0004% Fe 0.052%
Ni 0.024% Bi 0.001%
TOTAL 70.271%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The sample is very heavily corroded.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer:

Depth:

LAB NO: 1016**

EXCAVATION NO: 230/944

MUSEUM NO:

Plate Nos: 147-149

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Division, Bangkok

EXCAVATION REF:

DESCRIPTION: Fragment of circular section bracelet.

DIMENSIONS AND WEIGHT:

Diameter (section): 2 mm; original diameter of bracelet approx.8cm.

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 94-99%; Sn 1.9-7.4%; As 0.38%

ICP: Cu 86.149%; Sn 6.388%; Pb 0.013%; As 0.049%;
Sb 0.048%; Fe 0.079%; Ag 0.097%; Ni 0.004%
TOTAL 92.829%

METALLOGRAPHIC STRUCTURE:

α-dendrites in corroded eutectoid.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer:

Depth: 10-20 cm

LAB NO: 1017

EXCAVATION NO: 33/944

MUSEUM NO:

Plate Nos: 150-153

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Division, Bangkok.

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of rectangular section.

DIMENSIONS AND WEIGHT:

Section: 3x1 mm; original diameter: approx. 3.8 cm.

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 72.87%; Sn 22.68%; Pb 0.151%; As 0.228%; Sb 0.188%; Fe 0.271%; Ag 0.073%; Ni 0.400%; Co 0.005%; Bi 0.010%
Total 96.876%

EPMA: Cu 76.71-78.26%; Sn 23.12-23.82%; As 0.407%
Fe 0.221-0.309%; Sb 0.557%; Ag 0.347%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase grains in a matrix of β-martensite, with some retained β-phase.

COMMENTS:

The object was cast, slightly hot worked and heated up to the (α+β) range (798°-586°C) before quenching. Light olive-green patina characteristic of high tin bronzes. Cuprite inclusions.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1018A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 154-158

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of helically wound strip.

DIMENSIONS AND WEIGHT:

diameter (outer): 0.9 cm
thickness: 0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 77.00%; Sn 21.63%; Pb 0.143%; As 0.309%; Sb 0.170%; Fe 0.067%; Ag 0.129%; Ni 0.027%; Co 0.004%; Bi 0.067%

METALLOGRAPHIC STRUCTURE:

Twinned rounded α-phase in a background of acicular coarse needles of β-phase.

COMMENTS:

The object was cast, slightly worked in the hot state, and annealed in the (α+β) temperature range (798°-586°C) before quenching. Several such objects have been examined; they may be beads.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer:

Depth: 23 cm

LAB NO: 1018B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 159-162

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Small fragment of a container.

DIMENSIONS AND WEIGHT:

thickness: 1-1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: β-phase: Cu 75.95-76.81%; Sn 22.704-23.71%;
As 0.490%; Fe 0.354-0.786%; Sb 0.494-0.513%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in a short coarse acicular martensite, together with long-thin markings of banded martensite.

COMMENTS:

The object was cast and slightly hot-worked. It was then heated up to the (α+β) range (798^{o}-586^{o}C) and quenched.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1019

EXCAVATION NO: 72/944

MUSEUM NO:

Plate Nos: 163-169

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Helically wound strip.

DIMENSIONS AND WEIGHT:

height	0.5 cm
diameter (outer)	0.7 cm
thickness (section)	0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 76.5-77.47%; Sn 22.76-23.22%; As 0.368-0.448%
Fe 0.384-0.528%; Sb 0.463-0.674%; Au 0.338%

METALLOGRAPHIC STRUCTURE:

Twinned rounded α-phase in a background of acicular coarse needles of β-phase.

COMMENTS:

The object was cast, slightly worked in the hot state, and annealed to the ($\alpha+\beta$) temperature range (798^{o}C-586^{o}C) before quenching.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer:

Depth: 90-100 cm

LAB NO: 1020A*

EXCAVATION NO: 221/944

MUSEUM NO:

Plate Nos: 170

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Division, Bangkok.

EXCAVATION REF:

DESCRIPTION: Fragments of two bracelets corroded together.

DIMENSIONS AND WEIGHT:

length: 2 cm; diameter: 3 mm (each)

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 81.487%

ICP: Cu 90.676%; Sn 4.307%; Pb 0.130%; As 0.132%; Sb 0.120%; Fe 0.062%; Ag 0.051%; Ni 0.016%; Co 0.006%
Total 95.5%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

A very common type of circular section bracelet; these are usually cast.

CATALOGUE ENTRY

SITE:	KOK KHON	AREA:	Pit:	A2
LAB NO:	1020B		Layer:	
EXCAVATION NO:	221/944		Depth:	90-100 cm
MUSEUM NO:		Plate Nos:		
PERIOD:	Iron Age	Fig Nos:		
PRESENT LOCATION:	AD/B			

EXCAVATION REF:

DESCRIPTION: Fragment of helically wound strip, rectangular section.

DIMENSIONS AND WEIGHT:

diameter (outer) = 0.75 cm
thickness (section) = 0.5 mm ▯

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 52.631%

ICP: Cu 75.484%; Sn 21.481%; Pb 0.145%; As 0.244%;
Sb 0.253%; Fe 0.368%; Ag 0.241%; Ni 0.025%;
Co 0.004%; Bi 0.011%
Total 98.256%

METALLOGRAPHIC STRUCTURE:

COMMENTS: Similar to 1018A etc.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1021

EXCAVATION NO: 89/944

MUSEUM NO:

Plate Nos:

PERIOD:

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Small fragment of vessel, corroded.

DIMENSIONS AND WEIGHT:

thickness: ~1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 62.238%

ICP: Cu 74.69%; Sn 22.428%; Pb 0.127%; As 0.256%;
Sb 0.249%; Fe 0.066%; Ag 0.214%; Ni 0.024%;
Co 0.006%; Bi 0.038%
TOTAL 98.098%

METALLOGRAPHIC STRUCTURE:

Quenched high tin bronze.

COMMENTS:

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1022

EXCAVATION NO: 1/944

MUSEUM NO:

Plate Nos: 171-177

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: Cast "false wire" helix.

DIMENSIONS AND WEIGHT:

height: 2 cm
width: 1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.041%; Sn 2.228%; Pb 0.670%; Fe 0.019%

METALLOGRAPHIC STRUCTURE:

Polygonal grains with segregation of the impurities along the grain boundaries.

COMMENTS:

The object was cast and annealed.

CATALOGUE ENTRY

SITE: KOK KHON — AREA: Pit: A1

LAB NO: 1023** — Layer:

EXCAVATION NO: 195/944 — Depth:

MUSEUM NO: — Plate Nos: 178-181

PERIOD: Iron Age — Fig Nos:

PRESENT LOCATION: Archaeologocal Division, Bangkok.

EXCAVATION REF:

DESCRIPTION: A fragment of corroded bracelet with core material on inside. Section is C-shaped.

DIMENSIONS AND WEIGHT:

breadth: 0.8 cm
length: 3 cm
thickness (section): 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 90.3%; Sn 9.45%; S 0.002-0.08%; As 0.100%; Fe 0.14-0.15%; Sb 0.11-0.29%; Ni 0.055%; Ag 0.02%; Zn (trace); Au 0.10%

ICP: Cu 67.365%; Sn 12.429%; Fe 0.073%; Ag 0.282%
Total 80.149%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in partially corroded (α+δ) eutectoid.

COMMENTS:

The object was cast and fairly rapidly cooled. Lost wax casting was used, and the core material was not wholly removed.

CATALOGUE ENTRY

SITE:	KOK KHON	AREA:	Pit:
LAB NO:	1024		Layer:
			Depth:
EXCAVATION NO:	70/944		
MUSEUM NO:		Plate Nos:	182-193
PERIOD:	Iron Age		
		Fig Nos:	
PRESENT LOCATION:	AD/B		

EXCAVATION REF:

DESCRIPTION: Helically wound strip; 4 turns.

DIMENSIONS AND WEIGHT:

diameter (outer):	0.7 cm
height:	1.9 cm
section:	1.5 x 0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS: Similar to 1018A etc.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A1

Layer:

Depth: 109 cm

LAB NO: 1026

EXCAVATION NO: 271/944

MUSEUM NO:

Plate Nos: 184-188

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Division, Bangkok

EXCAVATION REF:

DESCRIPTION: Two fragments of circular section bracelet.

DIMENSIONS AND WEIGHT:

diameter of section: 0.3 cm ○
length: 3 cm and 2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 95-101%; Sn 1.45-5.5%; Pb 0.03-0.327%; S 0.02-0.09%; As 0.03-0.27%; Fe 0.03-0.14%; Sb 0.02-0.22%; Ni 0.03-0.17%; Ag 0.02-0.23%; Au 0.08-0.44%; Zn 0.005%

ICP: Cu 92.429%; Sn 3.88%; Pb 0.695%; As 0.183%; Sb 0.165%; Fe 0.024%; Ag 0.050%; Ni 0.028%; Co 0.004%; Bi 0.012%; Total 97.47%

METALLOGRAPHIC STRUCTURE:

Polygonal α- phase grains with very small areas of (α+δ) eutectoid.

COMMENTS:

The object was cast and partially annealed. There is segregation at the grain boundaries.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit: A2

Layer:

Depth: 100 cm

LAB NO: 1027B

EXCAVATION NO: 232

MUSEUM NO:

Plate Nos: 189-192

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: Archaeological Division, Bangkok.

EXCAVATION REF:

DESCRIPTION: A fragment of decorated bracelet with heavy corrosion.

DIMENSIONS AND WEIGHT:

Diameter (of the bracelet): 5 cm; section: 1.5 x 17 mm. 

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 78.740%

ICP: Cu 98.524%; Sn 5.936%; Pb 0.471%; As 0.197%; Sb 0.147%; Fe 0.033%; Ag 0.041%; Ni 0.023%; Co 0.005%; Bi 0.023%
Total 105.40%

METALLOGRAPHIC STRUCTURE:

α-dendrites in partially corroded $(\alpha+\delta)$ eutectoid.

COMMENTS:

The object was cast without subsequent heat treatment or working. The lost-wax casting simulated an embossed strip.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

LAB NO: 1028

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 193-196

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Socketed axe with corrosion on the surface. In some areas a good black patina appears.

DIMENSIONS AND WEIGHT: blade (thickness): <1 mm

socket: diameter (outer): 2.4 cm
(inner): 2.1 cm
(thickness): 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: α-phase: Cu 75.03-88.39%; Sn 11.62-21.63%;
Pb 0.036-6.118%; S 0.665%; Fe 0.114%;
Sb 0.528-0.765%

METALLOGRAPHIC STRUCTURE:

Probably α-dendrites with eutectoid in the interdendritic spaces.

COMMENTS:

The object was cast and slow cooled without any heat treatment or working, but is nevertheless a high tin bronze with a significant lead content.

CATALOGUE ENTRY

SITE: KOK KHON — AREA: Pit:

LAB NO: 1029 — Layer:

Depth:

EXCAVATION NO: No number; it was found on a survey in the same province as this site.

MUSEUM NO: — Plate Nos: 197-203

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: N.E.A.P., K.K.

EXCAVATION REF:

DESCRIPTION: 3 fragments of bracelet with decoration, in good condition, with residual core.

DIMENSIONS AND WEIGHT:

thickness (section): 1 mm
breadth " : 3 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 67.816%; Sn 7.71%; Pb 27.863%; As 0.226%; Sb 0.151%; Fe 0.046%; Ag 0.081%; Ni 0.023%; Co 0.004%; Bi 0.024%; Total 103.944%

METALLOGRAPHIC STRUCTURE:

α-phase with a lot of gas cavities and lead globules; uncorroded eutectoid in some areas. Lead globules are distributed throughout the specimen. In some areas one can see traces of dendrites although they are not clear.

COMMENTS:

The object was cast using the lost wax process, the core being totally enclosed in metal except for oval windows through which the core was supported in the mould investment. Bosses on the outer surface form an integral part of the casting. The lead content is particularly high.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1030

EXCAVATION NO: No number; it was found on a survey in the same province as this site.

MUSEUM NO:

Plate Nos: 204-206

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: N.E.A.P., K.K.

EXCAVATION REF:

DESCRIPTION: Complete bracelet, circular section.

DIMENSIONS AND WEIGHT:

diameter (outer): 4 cm
thickness: ~4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

The specimen was very corroded. There are some traces of α-dendrites in the corroded background of (α+δ) eutectoid.

COMMENTS:

The bracelet was cast.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1031

EXCAVATION NO: No number; it was found on a survey in Sakon Nakhon Province.

MUSEUM NO:

Plate Nos: 207-209

PERIOD:

Fig Nos:

PRESENT LOCATION: N.E.A.P., K.K.

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, corroded. The shape is rather distorted.

DIMENSIONS AND WEIGHT:

diameter (section): 2 mm 

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.528%; Sn 5.04%; Pb 0.526%; As 0.212%;
Sb 0.161%; Fe 0.013%; Ag 0.047%; Ni 0.028%;
Co 0.005%; Bi 0.015%
Total 98.575%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with a very small area of interdendritic structure (not very easily seen). What appear to be sulphite inclusions are present.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1032

EXCAVATION NO: 223/832

MUSEUM NO:

Plate Nos: 210-214

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: N.E.A.P., K.K.

EXCAVATION REF:

DESCRIPTION: Two fragments of bracelets fused together by corrosion products.

DIMENSIONS AND WEIGHT:

diameter (section): 0.4 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 91.7-93.1%; Sn 2.5-2.6%; S 0.061-0.064%; As 0.074%; Fe 0.170-0.176%; Sb 0.026%; Ag 0.067%; Au 0.07-0.30% Zn 0.054%

METALLOGRAPHIC STRUCTURE:

α-dendrites in a corroded ($\alpha+\delta$) eutectoid.

COMMENTS:

Cast; sulphide inclusions present.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1033

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 215

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Complete bracelet, terminal ends.

DIMENSIONS AND WEIGHT:

diameter (outer): 6 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Ag; Cu

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Thought originally to be bronze, this was found to be a silver artifact, made by thinning down the centre part of a bar and then bending into shape.

CATALOGUE ENTRY

SITE: KOK KHON

AREA: Pit:

Layer:

Depth:

LAB NO: 1034

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 216-219

PERIOD: Iron Age

Fig Nos:

PRESENT LOCATION: N.E.A.P., B.

EXCAVATION REF:

DESCRIPTION: A complete bracelet in good condition, circular section.

DIMENSIONS AND WEIGHT:

diameter (outer): 8.9 cm
section: 7.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 87.727%; Sn 2.94%; Pb 0.953%; As 0.202%; Sb 0.128%; Fe 0.017%; Ag 0.034%; Ni 0.023%; Co 0.004%; Bi 0.016%;
Total 92.044%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with a very small area of interdendritic structure (not very easily seen).

COMMENTS:

The object was cast.

Site 2. NON CHAI

Amphoe Müang, Khon Kaen Province
Latitude 16°27'40"N; Longitude 102°61'40"E.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1101

EXCAVATION NO: NC 1217

MUSEUM NO:

Plate Nos: 220-223

PERIOD: Protohistoric, Iron Age, 0-500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet with spherical relief decoration, corroded, but some metal core left. The bracelet was chemically cleaned.

DIMENSIONS AND WEIGHT:

length (fragment): 2.1 cm; width (fragment): 1.2 cm
thickness (section): 1.5-2 mm; diameter (bracelet): approx. 4 cm.

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 77.268%

ICP: Cu 87.969%; Sn 6.794%; Pb 0.627%; As 0.141%; Sb 0.144%;
Fe 0.224%; Ag 0.039%; Ni 0.018%; Co 0.006%; Bi 0.016%;
Total 95.981%

METALLOGRAPHIC STRUCTURE:

α-dendrites in corroded eutectoid with some lead globules. The area of eutectoid is reasonably large, indicating a fairly high tin content in the alloy. There are some black lead globules distributed in the sample.

COMMENTS:

The bracelet was cast and slowly cooled. The decoration was an integral part of the lost wax casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1102

EXCAVATION NO: NC 1896

MUSEUM NO:

Plate Nos: 224-228

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of solid D-section bracelet, corroded.

DIMENSIONS AND WEIGHT:

thickness (section):	1	mm
breadth (bracelet):	0.4	cm
diameter (bracelet):	5	cm

D

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 44.78-53.6%; Sn 16.02-18.59%; Pb 7.35-9.74%
AA: Cu 64.368%
ICP: Cu 80.146%; Sn 15.182%; Pb 6.277%; As 0.651%;
Sb 0.235%; Fe 0.090%; Ag 0.209%; Ni 0.076%;
Co 0.012%; Bi 0.171%;
Total 103.049%

METALLOGRAPHIC STRUCTURE:

The sample was extremely corroded. There is no clear evidence of dendrites. The structure looks like polygonal grains, but there are some features looking like eutectoid in the inter-dendritic area. Lead globules distributed throughout the specimen.

COMMENTS:

The object was cast and annealed.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1103

EXCAVATION NO: NC 846

MUSEUM NO:

Plate Nos: 229

PERIOD: Protohistoric, Iron Age, 0-500 AD.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a square section bracelet.

DIMENSIONS AND WEIGHT:

section: 4 x 4 mm □

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 43.679%

ICP: Cu 49.878%; Sn 25.590%; Pb 0.153%; As 0.051%;
Sb 0.238%; Fe 0.101%; Ag 0.010%; Ni 0.015%; Co 0.006%
Total 76.042%

METALLOGRAPHIC STRUCTURE:

COMMENTS: Solid cast tin bronze.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1104

EXCAVATION NO: NC 814

MUSEUM NO:

Plate Nos: 230-232

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of oval section.

DIMENSIONS AND WEIGHT:

diameter (bracelet): ≃6 cm
section: 3 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 69.973%; Sn 6.719%; Fe 0.058%
Total 76.750%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well-developed form, with a very small amount of eutectoid and no lead globules.

COMMENTS:

The object was cast and slowly cooled.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1105

EXCAVATION NO: NC 2147

MUSEUM NO:

Plate Nos: 233-237

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a D-section ring.

DIMENSIONS AND WEIGHT:

section: 8 x 1.5 mm D
diameter: ≈2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 75.59-84.81%; Sn 13.16-22.88%; As 0.701-1.25%

ICP: Cu 67.492%; Sn 21.981%; As 0.924%; Fe 1.329%; Ag 0.088%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase forming a pattern similar to the Widmanstätten structure. Some of the α-phase is rounded, and some is in an elongated form, on a background of β-phase. Grayish blue cuprite inclusions.

COMMENTS:

The object was cast, then heated up to the (α+β) region and worked, then annealed at a temperature above 520°C (between 520°-586°C) and quenched in water.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1106

EXCAVATION NO: NC 818

MUSEUM NO:

Plate Nos: 238-241

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION:

A fragment of D-section bracelet.

DIMENSIONS AND WEIGHT:

section: 2 x 5 mm D

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Background: Cu 85.172-90.97%; Sn 10.29-13.59%; Pb (trace)
Features looking like dendrites: Cu 7.29-22.42%;
Sn 40.66-54.24%; Pb 14.36-15.34%; Sb 2.17%; S, As (trace)
Metallic inclusions: Cu, (Sn absent), Cuprite rim

ICP: Cu 59.751%; Sn 12.858%; Pb 3,400%; Fe 0.998%
Total 77.007%

METALLOGRAPHIC STRUCTURE:

The structure looks like small dendrites in a background looking similar to ($\alpha+\delta$) eutectoid (under low magnification). Under higher magnification, the background consisted of a very small white phase in unresolved dark matrix. There are many forms of the white phase, some are leaf-like, some look like particles.

COMMENTS:

The interpretation of this structure is not certain. It may be that the object was cast, but not worked. The unusual structure may be caused by the presence of other elements (e.g. Sb). Metallic inclusions (copper) are found in the structure.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D4

Layer: (19)

Depth:

LAB NO: 1107

EXCAVATION NO: NC 748/234

MUSEUM NO:

Plate Nos: 242-245

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION:

A nearly complete ring, corroded and very thin. The section is square.

DIMENSIONS AND WEIGHT:

diameter (ring): '1.2 cm
section: 1 x 1 mm □

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: dendrite: Cu 87.28-93.97%; Sn 4.768-9.634%; As 0814-1.297% sulphide inclusion, lead inclusion, metallic inclusion (Cu).

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in $(\alpha+\delta)$ eutectoid. The amount of $(\alpha+\delta)$ eutectoid is rather low. There are metallic inclusions (Cu), sulphide inclusions, and lead globules in the specimen.

COMMENTS:

The object was cast, and not worked.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D_1

Layer: (32)

Depth:

LAB NO: 1108

EXCAVATION NO: NC 1390/626

MUSEUM NO:

Plate Nos: 246

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A complete ring, with heavy corrosion. The ends touch but do not join.

DIMENSIONS AND WEIGHT:

diameter (ring): 2.8 cm (outer)
1.8 cm (inner)

thickness: 0.5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 58.335%

ICP: Cu 71.513%; Sn 5.257%; Pb 0.430%; As 0.079%;
Sb 0.118%; Fe 0.120%; Ag 0.054%; Ni 0.013%;
Co 0.004%; Bi 0.006%
Total 77.594%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Probably bent into a circular shape.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D2

LAB NO: 1109

Layer: (33)

Depth:

EXCAVATION NO: NCI 467/659

MUSEUM NO:

Plate Nos: 247 - 250

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of D-section bracelet.

DIMENSIONS AND WEIGHT:

section: 3 x 1.5 mm D
diameter: 3 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 91.25-91.64%; Sn 8.94-9.31%

ICP: Cu 87.892%; Sn 11.927%; Pb 2.526%; As 0.187%; Sb 0.236%; Fe 0.017%; Ag 0.104%; Ni 0.031%; Co 0.005%; Bi 0.010% Total 102.747%

AA: Cu 73.125%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in a small area of eutectoid. There are also some lead particles in the structure.

COMMENTS:

The object was cast and rapidly cooled.

CATALOGUE ENTRY

SITE: NON CHAI

LAB NO: 1110

EXCAVATION NO: NC 1579 676

AREA: Pit:

Layer:

Depth:

MUSEUM NO:

Plate Nos: 251-254

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A ring, nearly complete.

DIMENSIONS AND WEIGHT:

diameter (section) = 2.5 mm 
diameter (ring, outer) = 1.7 cm
diameter (ring, inner) = 1.1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 92.43-95.29%; Sn 3.82-7.64%

ICP: Cu 78.925%; Sn 8.510%; Pb 7.145%; As 0.203%; Sb 0.149%
Fe 0.299%; Ag 0.038%; Ni 0.024%; Co 0.007%; Bi 0.016%
Total 95.316%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in $(\alpha+\delta)$ eutectoid. The amount of $(\alpha+\delta)$ eutectoid is rather low. A large amount of lead globules.

COMMENTS:

The object was cast without further working or heat treatment.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D4

Layer: (26)

Depth:

LAB NO: 1111

EXCAVATION NO: NC 993 456

MUSEUM NO:

Plate Nos: 255-259

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of circular section bracelet.

DIMENSIONS AND WEIGHT:

diameter (bracelet): approx. 4.0 cm
diameter (section): 1.5 mm ○

COMPOSITION: (XRF; EPMA; AA; ICP)

EMPA: Cu 86.28-94.75%; Sn 5.23-11.33%; Pb 5.217%; As 1.70-2.24%
Metallic inclusion (copper)
Lead particle >99.05%
AA: Cu 69.324%
ICP: Cu 82.193%; Sn 8.999%; Pb 15.113%; As 0.578%; Sb 0.325%
Fe 0.039%; Ag 0.206%; Ni 0.056%; Co 0.012%; Bi 0.061%
Total 107.582%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small area of interdendritic structure. There are also some lead particles in the structure.

COMMENTS: The object was cast and rapidly cooled.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1112

EXCAVATION NO: NC 1002/460

MUSEUM NO:

Plate Nos: 260-262

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: An ornament of unknown use.

DIMENSIONS AND WEIGHT:

thickness:	~ 1 mm
diameter (outer):	0.9 cm
diameter (inner):	0.6 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in very small areas of (α+δ) eutectoid (hardly seen under an optical microscope). The α-dendrites are of a rather small size.

COMMENTS:

The object must have been cast and rapidly cooled. From the structure, the tin content should be low. There are some lead globules in the specimen.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1113

EXCAVATION NO: NC 1975/975

MUSEUM NO:

Plate Nos: 263

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: Bracelet, badly corroded, decorated with 4 bosses, solid cast.

DIMENSIONS AND WEIGHT:

diameter: 5 cm
section: 4 x 23 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 72.778%; Sn 2.959%; Pb 0.074%; Fe 0.166%
Total 75.978%

METALLOGRAPHIC STRUCTURE:

COMMENTS: Lost wax casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D2

Layer: (28)

Depth:

LAB NO: 1115

EXCAVATION NO: NC 1200 673 or 613

MUSEUM NO:

Plate Nos: 264-266

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, corroded. The decoration is in spherical relief. Core material used in casting still remains inside the rounded bosses.

DIMENSIONS AND WEIGHT:

width (bracelet): 1.8 cm
thickness (section): 1.5-2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 83.160%
ICP: Cu 100.036%; Sn 4.621%; Pb 0.823%; As 0.173%;
Sb 0.163%; Fe 0.023%; Ag 0.119%; Ni 0.023%;
Co 0.006%.

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure.

COMMENTS:
The object was cast and slowly cooled. The technology is the same as object no. 1124.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1116

EXCAVATION NO: NC 914

MUSEUM NO:

Plate Nos: 267-273

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Bracelet with a bell. The bracelet is of circular section, and the bell contains a stone. The section was taken from the bracelet.

DIMENSIONS AND WEIGHT:
section: 5 mm
bell (dia.): 2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)
EPMA: Cu 94.32-96.82%; Sn 3.86-6.41%; Pb 0.25-0.45%; As 0.305-0.676%.
ICP: Cu 77.159%; Sn 5.65%; Pb 10.831%; As 0.731%; Sb 0.188%; Fe 0.071%; Ag 0.068%; Ni 0.053%; Co 0.007%; Bi 0.096%
Total 94.854%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in a eutectoid. The size of the dendrites is large. Some casting cavities and black lead particles.

COMMENTS:
The object must have been cast and air cooled. The bell and bracelet were cast together in one piece using the lost wax process.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1117

EXCAVATION NO: NC 342

MUSEUM NO:

Plate Nos: 274-283

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bronze bell, very corroded, with circular relief decoration.

DIMENSIONS AND WEIGHT:

diameter of the bell:	1.6-1.8 cm
thickness:	1-3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 74.637%

ICP: Cu 84.098%; Sn 13.404%; Pb 1.744%; As 0.264%; Sb 0.241%; Fe 0.200%; Ag 0.1004%; Ni 0.031%; Co 0.007%; Bi 0.036%
Total 100.125%

METALLOGRAPHIC STRUCTURE:

α-dendrites in a background of eutectoid. There is a very small amount of metal in a rectangular area remaining in the loop.

COMMENTS:

The bell was cast using the lost wax process.

CATALOGUE ENTRY

SITE:	NON CHAI	AREA:	Pit:	D2
LAB NO:	1118		Layer:	(6)
EXCAVATION NO:	NC 438		Depth:	
MUSEUM NO:		Plate Nos:		284-290
PERIOD:	Protohistoric, Iron Age	Fig Nos:		
PRESENT LOCATION:	AD/B			

EXCAVATION REF:

DESCRIPTION: Fragment of bracelet of triangular section. The patina is dark green.

DIMENSIONS AND WEIGHT:

width (section): 3.5mm
diameter (bracelet): ~5cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 68.826%

ICP: Cu 82.576%; Sn 22.173%; Pb 0.234%; As 0.202%; Sb 0.396%; Fe 2.295%; Ag 0.395%; Ni 0.069%; Co 0.011%; Bi 0.016%;
Total 108.367%

METALLOGRAPHIC STRUCTURE:

Structure of twinned α-phase on a background of β-martensite. The β-needles seem to fill the original β-grain. The amount of α-phase was very small, and the α-phase was also small and rounded.

COMMENTS:
This object must have been cast, heated up to the (α+β) region, and worked. Then the object was heated up to above 586°C (in the (α+β) region) and quenched in water. There was also evidence of elongated cuprite inclusions lying perpendicular to the direction of working.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D4

LAB NO: 1119

Layer: (4)

Depth: 90 cm

EXCAVATION NO: NC 77, 28/1, 28/2

MUSEUM NO:

Plate Nos: 291-295

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of a ring. The patina is dark green. The section of a ring is nearly rectangular.

DIMENSIONS AND WEIGHT:

diameter	(outer):	1.7 cm
	(inner):	1.6 cm
section:		4 x 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 77.28-79.805%; Sn 19.830-22.039%; As 0.960-1.108%; Pb 0.101%; Fe 0.436-0.645%; Sb 0.395-0.700%

ICP: Cu 75.366%; Sn 22.041%; As 0.781%; Fe 2.295%; Ag 0.145%
Total 100.629%

METALLOGRAPHIC STRUCTURE:

β-martensite (very compact, short, and fine). There are very small areas of α-phase scattered all over in a background of β-martensite.

COMMENTS:

The object was cast then heated up to the (α+β) region (798°-586°C) and then quenched into water.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1

Layer: (41)

Depth:

LAB NO: 1120

EXCAVATION NO: NC 2015

MUSEUM NO:

Plate Nos: 296-301

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, very corroded. X-radiography revealed some relief decoration on the surface.

DIMENSIONS AND WEIGHT:

section (lunate): 6 x 1.5 mm
bracelet diameter: ~5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 84.685%; Sn 9.549%; Pb 3.268%; As 0.107%; Sb 0.034%; Fe 0.160%;
Total 97.803%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure. There are also some lead particles in the structure.

COMMENTS:

The object was cast by the lost wax process and rapidly cooled. The decoration is an integral part of the casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1

Layer: (40)

Depth:

LAB NO: 1121A

EXCAVATION NO: NC 1915 / 974

MUSEUM NO:

Plate Nos: 302-304

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A complete bracelet. The X-radiograph showed that the object was decorated on the surface. This bracelet has unusual catches.

DIMENSIONS AND WEIGHT:

diameter (bracelet): 6.2 cm
breadth: 1.1 cm
thickness (section): 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 79.051%

ICP: Cu 90.065%; Sn 7.853%; Pb 3.456%; As 0.296%; Sb 0.242%
Fe 0.028%; Ag 0.131%; Ni 0.039%; Co 0.008%; Bi 0.023%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Similar to object no. 1120. For discussion of the fastening see section 6.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1121B

EXCAVATION NO: 1915

MUSEUM NO:

Plate Nos: 305-306

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two small fragments of bracelet, with decoration. X-radiograph reveals decoration.

DIMENSIONS AND WEIGHT:

section: 11.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 74.157%

ICP: Cu 98.191%; Sn 7.734%; Pb 3.541%; As 0.262%;
Sb 0.236%; Fe 0.031%; Ag 0.140%; Ni 0.036%;
Co 0.006%; Bi 0.018%
Total 110.195%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure.

COMMENTS:

The object was cast and mechanically finished.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1/D2

LAB NO: 1123

Layer: (45)

Depth:

EXCAVATION NO: NC 2486

MUSEUM NO:

Plate Nos: 307-308

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, corroded, with core material inside.

DIMENSIONS AND WEIGHT:

section: 1.1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 94.25%

ICP: Cu 91.880%; Sn 2.356%; Pb 0.726%; As 0.167%; Sb 0.145%
Fe 0.048%; Ag 0.052%; Ni 0.028%; Co 0.008:
Total 95.410%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Lost wax casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D2

Layer: (27)

Depth:

LAB NO: 1124

EXCAVATION NO: NC 1181

MUSEUM NO:

Plate Nos: 309-314

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a flat bracelet, decorated with round bosses.

DIMENSIONS AND WEIGHT:

section: 15 x 1.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 83.616%

ICP: Cu 96.446%; Sn 3.984%; Pb 0.448%; As 0.170%; Sb 0.142%
Fe 0.038%; Ag 0.116%; Ni 0.024%; Co 0.007%
Total 101.375%

EPMA: Cu 95.115-95.722%; Sn 2.58-5.17%
Metallic inclusion (Cu)

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure.

COMMENTS:

The object was cast by the lost wax process. There are metallic inclusions.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1

LAB NO: 1125

Layer: (38)

Depth:

EXCAVATION NO: NC 1818

MUSEUM NO:

Plate Nos: 315-318

PERIOD: Protohistoric Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, corroded. X-radiography revealed decoration and catches which were in the closed position.

DIMENSIONS AND WEIGHT:

diameter: 5 cm
section: 6 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 78.387%
ICP: Cu 91.014%; Sn 9.724%; Pb 3.717%; As 0.254%; Sb 0.235%; Fe 0.055%; Ag 0.100%; Ni 0.o37%; Co 0.006%; Bi 0.012%; Total 105.154%
EPMA: Cu 93.59-96.8%; Sn 3.56-5.58%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure. There are also some lead particles.

COMMENTS:

The object was cast by the lost wax process, and rapidly cooled.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D3

Layer: (37)

Depth:

LAB NO: I127

EXCAVATION NO: NC 1941

MUSEUM NO:

Plate Nos: 319-320

PERIOD: Protohistoric Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet with decoration

DIMENSIONS AND WEIGHT:

section: 12 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 77.02%

ICP: Cu 95.915%; Sn 7.904%; Pb 4.917%; As 0.210%; Sb 0.222%; Fe 0.191%; Ag 0.179%; Ni 0.030%; Co 0.007%; Bi 0.020%; Total 109.595%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure. There are also some lead particles.

COMMENTS:

The object was cast by the lost wax process, and rapidly cooled. The microstructure is the same as 1125.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D3/D4

LAB NO: 1128

Layer: (46)

Depth:

EXCAVATION NO: NC 2358

MUSEUM NO:

Plate Nos: 321-323

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small piece of a bracelet, with decoration and heavy corrosion. The decoration was in the form of raised bosses.

DIMENSIONS AND WEIGHT:

section: 18 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 74.603%

ICP: Cu 94.385%; Sn 9.206%; Pb 0.419%; As 0.106%; Sb 0.165%; Fe 0.062%; Ag 0.075%; Ni 0.027%; Co 0.009%; Bi 0.025%; Total 103.479%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well-developed form, with a little inter-dendritic eutectoid and some lead globules.

COMMENTS:
The object was cast and slowly cooled. The technology is the same as object no. 1124.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D3/D4

LAB NO: 1128

Layer: (46)

Depth:

EXCAVATION NO: NC 2358

MUSEUM NO:

Plate Nos: 321-323

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small piece of a bracelet, with decoration and heavy corrosion. The decoration was in the form of raised bosses.

DIMENSIONS AND WEIGHT:

section: 18 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 74.603%

ICP: Cu 94.385%; Sn 8.206%; Pb 0.419%; As 0.106%; Sb 0.165%; Fe 0.062%; Ag 0.075%; Ni 0.027%; Co 0.009%; Bi 0.025%; Total 103.479%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well-developed form, with a little interdendritic eutectoid and some lead globules.

COMMENTS:

The object was cast and slowly cooled. The technology is the same as object no. 1124.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1

Layer: (40)

Depth:

LAB NO: 1129A

EXCAVATION NO: NC 1915 / 973

MUSEUM NO:

Plate Nos: 324-325

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, with decoration on the surface, and a catch.

DIMENSIONS AND WEIGHT:

section: 17 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 81.301%

ICP: Cu 88.773%; Sn 6.269%; Pb 2.381%; As 0.203%; Sb 0.216%; Fe 0.040%; Ag 0.108%; Ni 0.030%; Co 0.008%; Bi 0.008%;
Total 98.036%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well-developed form with a little interdendritic eutectoid and some lead globules. Large casting cavities were found in the specimen.

COMMENTS:

The object was made by the lost wax process and slowly cooled. The microstructure is the same as 1125.

CATALOGUE ENTRY

SITE: NON CHAI

LAB NO: 1129B

EXCAVATION NO: NC 1915/973

MUSEUM NO:

AREA: Pit: D1

Layer: $\overline{(40)}$

Depth:

Plate Nos: 327-328; also 324, 326.

Fig Nos:

PERIOD: Protohistoric, Iron Age.

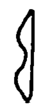
PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet with decoration on the surface.

DIMENSIONS AND WEIGHT:

section: 17 x 2 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 84.122%

ICP: Cu 91.977%; Sn 6.554%; Pb 3.817%; As 0.228%
Sb 0.222%; Fe 0.023%; Ag 0.116%; Ni 0.034%
Co 0.007%; Bi 0.016%;
Total 102.994%

METALLOGRAPHIC STRUCTURE:

The same as 1129A.

COMMENTS:

As for 1129A.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1

Layer: (40)

Depth:

LAB NO: 1129C

EXCAVATION NO: NC 1915/973

MUSEUM NO:

Plate Nos: the same as 1129B
Pl. 327-328

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet with decoration on the surface.

DIMENSIONS AND WEIGHT:

section: 11 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 79.475%

ICP: Cu 88.284%; Sn 6.471%; Pb 2.088%; As 0.257%; Sb 0.232%;
Fe 0.078%; Ag 0.128%; Ni 0.036%; Co 0.008%; Bi 0.006%;
Total 97.586%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure. There are also some lead particles in the structure.

COMMENTS:

The object was cast and rapidly cooled.
The same as 1129A.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1/D2

LAB NO: 1130

Layer: (45)

Depth:

EXCAVATION NO: NC 2491

MUSEUM NO:

Plate Nos: 329-330

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION:

Fragment of a bracelet. X-radiography shows decoration and a catch at one end of the bracelet.

DIMENSIONS AND WEIGHT:

thickness (section): 1 mm
breadth (bracelet): 1.1 cm
diameter (bracelet): 6 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 79.848%

ICP: Cu 99.356%; Sn 5.872%; Pb 3.074%; As 0.190%; Sb 0.192%
Fe 0.074%; Ag 0.101%; Ni 0.033%; Co 0.005%
Total 107.897%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well-developed form with a little interdendritic eutectoid and some lead inclusions.

COMMENTS:

The object was made by lost wax casting and slow cooling.
The same as 1125.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: from survey

Layer:

Depth:

LAB NO: 1131A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 331-332

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A very corroded piece of a bronze bracelet with decoration.

DIMENSIONS AND WEIGHT:

section: 16 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 84.749%; Sn 7.16%; Pb 0.321%; As 0.134%; Sb 0.145%;
Fe 0.024%; Ag 0.038%; Ni 0.021%; Co 0.004%; Bi 0.018%;
Total 92.614%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure.

COMMENTS:

The bracelet was made by lost wax casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

LAB NO: 1131B

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 333-337

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a circular section bracelet with line decoration on the surface. There is a catch at one end of the bracelet.

DIMENSIONS AND WEIGHT:

diameter (section): 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
EPMA: dendrite: Cu 89.13-94.29%; Sn 5.68-9.32%; Pb 0.506-0.826%; As 0.384-1.027%; Fe 0.372%; Sb 0.581%
lead particle

ICP: Cu 82.489%; Sn 7.44%; Pb 16.856%; As 0.227%; Sb 0.174%; Fe 0.036%; Ag 0.067%; Ni 0.025%; Co 0.006%; Bi 0.024%; Total 107.344%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure. There are also casting cavities and lead particles.

COMMENTS:

The bracelet was cast and cooled fairly rapidly.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1132

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 338-339

PERIOD:

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of bronze which may be from a large bell or vessel.

DIMENSIONS AND WEIGHT:

thickness: 2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 70.13-77.78%; Sn 5.41-8.49%
Metallic inclusion.

AA: Cu 78.51%

ICP: Cu 86.25%; Sn 6.44%; Pb 1.22%; As 0.229%; Sb 0.159%; Fe 0.041%; Ag 0.057%; Ni 0.021%; Co 0.007%; Bi 0.011%;
Total 94.433%

METALLOGRAPHIC STRUCTURE:

α-dendrites in (α+δ) eutectoid. The amount of eutectoid is rather small. There are also casting cavities.

COMMENTS: The object was cast.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1133C

EXCAVATION NO:

MUSEUM NO:

Plate Nos: As for 1133A and 1133B 340-342

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment from a group of 3 decorated bracelets with heavy corrosion products.

DIMENSIONS AND WEIGHT:

section: 16 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 89.958%; Sn 6.547%; Pb 0.117%; As 0.030%; Fe 0.054%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 1131 A and B.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

LAB NO: 1134

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 343-344

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A bracelet from a group of 4 bracelets with associated bone. The bracelet was corroded very badly. The decorations are bosses and lines.

DIMENSIONS AND WEIGHT:

section: 25 x 2.5mm
diameter: 4.9-6.3 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 88.300%

ICP: Cu 99.468%; Sn 6.434%; Pb 0.364%; As 0.129%; Sb 0.151%; Fe 0.037%; Ag 0.041%; Ni 0.023%; Co 0.007%
Total 95.654%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Lost wax casting.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1135A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 345

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet with decoration in the form of raised bosses.

DIMENSIONS AND WEIGHT:

section: 16 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 97.35-98.29%; Sn 2.66-3.88%

AA: Cu 82.543%

ICP: Cu 98.79%; Sn 7.60%; Pb 0.438%; As 0.190%; Sb 0.164%
Fe 0.085%; Ag 0.041%; Ni 0.023%; Co 0.005%; Bi 0.022%
Total 107.369%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very small areas of interdendritic structure.

COMMENTS:

The object was made by lost wax casting.
As for 1125.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1135B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 345 (as for 1135A)

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet (see 1135A).

DIMENSIONS AND WEIGHT:

same as 1135A

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

α-dendrites in small areas of corroded eutectoid.

COMMENTS:
The object was cast by the lost wax process.
As for 1125.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1136A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 346

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, with raised bosses.

DIMENSIONS AND WEIGHT:

section: 16 x 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 96.183-97.425%; Sn 2.424-3.360%; Fe 0.249%

METALLOGRAPHIC STRUCTURE:

α-dendrites with a small area of corroded eutectoid.

COMMENTS:

The object was cast and slow cooled.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1136B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 347-348

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet which is broken in 2 pieces. The catches are still in the closed position.

DIMENSIONS AND WEIGHT:

section: 16 x 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.409%; Sn 6.628%; Pb 2.126%; Fe 0.131%;
Total 92.295%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well developed form with a little interdendritic eutectoid and some lead globules.

COMMENTS:

The object was cast and slow cooled.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

LAB NO: 1137

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 349-352

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a bracelet, in form of twisted strands.

DIMENSIONS AND WEIGHT:

section approximately semi-circular: 2 x 1.3 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 98.379%

ICP: Cu 83.176%; Sn 3.856%; Pb 0.325%; As 0.154%; Sb 0.135%; Fe 0.049%; Ag 0.031%; Ni 0.019%; Co 0.008%
Total 87.753%

METALLOGRAPHIC STRUCTURE:

The structure revealed the α-phase, with very large gas porosities and shrinkage voids. There is no sign of α-dendrites. The α-phase appeared on a white background and the gas porosities or casting cavities appeared as black dots. There are some small lead globules in some areas.

COMMENTS:

The object was cast and annealed. It was cast in one piece without evidence of working. The appearance of a twisted shape was made by the lost wax casting technique.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1138

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 353-354

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small spherical bell with spiral relief decoration. A broken loop is on top of the bell.

DIMENSIONS AND WEIGHT:

height: 1.5 cm
width: 1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The object was not sampled for chemical analysis and metallography. From the information obtained from object 1117, it may be possible to predict the technology of this object. It should be cast by lost wax process and also should have similar composition.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D2/D3

Layer: (36)

Depth:

LAB NO: 1139

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 355-357

PERIOD: Protohistoric, Iron Age.

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small spherical bell with spiral relief decoration and loop, very corroded. It was chemically cleaned.

DIMENSIONS AND WEIGHT:

height: 1.8 cm
width: 1.2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The same as 1138.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: D1/D2

Layer: (30)

Depth:

LAB NO: 1140

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 358

PERIOD: Protohistoric, Iron Age

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A distorted bell with loop but no decoration.

DIMENSIONS AND WEIGHT:

height: 1.8 cm
width: 1.5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS:
The manufacture technique should be the same as 1117,1138,1139.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1142A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 359-365

PERIOD:

Fig Nos:

PRESENT LOCATION: N.E.A.U./K.K.

EXCAVATION REF:

DESCRIPTION: A fragment from a large bell (from the lower part). The bell has a loop on the top.

DIMENSIONS AND WEIGHT:

height: 10 cm
width: 7 cm
thickness: ~2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

α-dendrites with very small areas of eutectoid. In some areas the α-dendrite is cored. In some areas the meeting place of each dendrite gives very clear boundaries.

COMMENTS:

The object was cast and should have a low tin content. There is no evidence of working or heat treatment.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1142B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 359-360; 366-368

PERIOD:

Fig Nos:

PRESENT LOCATION: NEAU/KK

EXCAVATION REF:

DESCRIPTION: It is a fragment from the same object as 1142A. The fragment was taken from the top part of 1142A.

DIMENSIONS AND WEIGHT:

height: 10 cm
width: 7 cm
thickness: ≈2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Similar to 1142A.

-

COMMENTS:

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1143

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 369-375

PERIOD:

Fig Nos:

PRESENT LOCATION: NEAU/KK

EXCAVATION REF:

DESCRIPTION: A small fragment from a bell.
The shape of the bell is quite unusual.

DIMENSIONS AND WEIGHT:

thickness: 2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 79.49-84.76%; Sn 3.44-9.13%
AA: Cu 84.517%
ICP: Cu 87.50%; Sn 7.955%; Pb 2.984%; As 0.363%; Sb 0.186%; Fe 0.053%; Ag 0.091%; Ni 0.028%; Co 0.008%; Bi 0.026%; Total 99.194%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in small areas of eutectoid. Lead particles distributed all over the specimen. Sulphide inclusions seen in structure and identified by EPMA.

COMMENTS:

The object was cast without further working or heat treatment.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1145A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 376-378

PERIOD: Protohistoric Iron Age

Fig Nos:

PRESENT LOCATION: NEAU/KK

EXCAVATION REF:

DESCRIPTION: Two fragments of a very corroded bracelet with relief bosses.

DIMENSIONS AND WEIGHT:

section: 25 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 84.039%

ICP: Cu 83.475%; Sn 8.493%; Pb 0.342%; As 0.141%; Sb 0.169%; Fe 0.039%; Ag 0.047%; Ni 0.023%; Co 0.006%
Total 92.735%

METALLOGRAPHIC STRUCTURE:

There is no clear evidence of dendrites. The structure appears to be a white background of α-phase, with intergranular corrosion products in some areas.

COMMENTS·

The object was cast by the lost wax process and annealed.

CATALOGUE ENTRY

SITE: NON CHAI

AREA: Pit:

Layer:

Depth:

LAB NO: 1145B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 379-383

PERIOD: Protohistoric Iron Age

Fig Nos:

PRESENT LOCATION: NEAU/KK

EXCAVATION REF:

DESCRIPTION: Fragment of a corroded bracelet with round bosses as decoration. There are some remains of core material in the raised areas.

DIMENSIONS AND WEIGHT:

section: 25 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 76.132%

ICP: Cu 95.639%; Sn 3.244%; Pb 0.373%; As 0.137%; Sb 0.115%; Fe 0.092%; Ag 0.040%; Ni 0.022%; Co 0.006%
Total 99.668%

METALLOGRAPHIC STRUCTURE:

There is no clear evidence of dendrites. The structure appears to be a white background of α-phase with intergranular corrosion products in some areas.

COMMENTS:

As for 1145A.

3. MISCELLANEOUS SITES

CATALOGUE ENTRY

SITE: LOPBURI ARTILLERY CENTRE SITE, Lopburi Province

AREA: Pit:

Layer:

Depth:

LAB NO: 1901B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 384-386

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: National Museum, Lopburi.

EXCAVATION REF:

DESCRIPTION: Broken ring, rectangular section with convex outer surface.

DIMENSIONS AND WEIGHT:

diameter (external): 2.1 cm
diameter (internal): 1.7 cm
thickness: 0.2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Dendrite: Cu 88.28-89.67%; Sn 11.50-11.93%; Pb,As,Fe traces.
Interdendritic: Cu 7.04-9.80%; Sn 40.01-43.76%; Pb 15.68-19.82%
S 0.624-0.93%; As 1.27-1.62%; Fe 0.607%;
Sb 0.960-1.031%; Ag 0.79-0.88%
Black dot: Cu 54.73%; Sn 11.203%; Pb 0.863%

METALLOGRAPHIC STRUCTURE:

Corroded dendritic structure of α-phase in corroded $(\alpha+\delta)$ eutectoid. The amount of $(\alpha+\delta)$ eutectoid is very small. There are casting cavities and inclusions which may be cuprite (gray-blue). There are some lead globules in the sample.

COMMENTS:

The object was cast and slowly cooled. The inclusions in the object may be cuprite and sulphides.

CATALOGUE ENTRY

SITE: LOPBURI ARTILLERY CENTRE SITE
Lopburi Province

AREA: Pit:

Layer:

Depth:

LAB NO: 1901C

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 387-389

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: National Museum, Lopburi

EXCAVATION REF:

DESCRIPTION: A fragment of a ring

DIMENSIONS AND WEIGHT:

thickness: approx. 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: dendrite: Cu 87.017%; Sn 12.998%; Pb and As traces.
lead inclusion

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in the corroded (α+δ) eutectoid. There are a lot of large casting cavities and some black dots, possibly lead globules.

COMMENTS:

The object was cast and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: LOPBURI ARTILLERY CENTRE SITE, Lopburi Province.

AREA: Pit:

Layer:

Depth:

LAB NO: 1901D

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 390-391

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: National Museum, Lopburi.

EXCAVATION REF:

DESCRIPTION: Small fragment of a ring.

DIMENSIONS AND WEIGHT:

thickness: 0.2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: dendrite: Cu 77.12%; Sn 11.59-14.93%; Pb 1.081%; S, As, Fe traces

METALLOGRAPHIC STRUCTURE:

longitudinal section: very corroded but one can detect the α-dendritic structure with (α+δ) eutectoid. Black dots of lead globules distributed all over the specimen.

COMMENTS:

The object was cast. From this longitudinal section, one cannot obtain any other information.

CATALOGUE ENTRY

SITE: LOPBURI ARTILLERY CENTRE SITE
Lopburi Province

AREA: Pit:

Layer:

Depth:

LAB NO: 1901F

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 392-393

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: National Museum, Lopburi.

EXCAVATION REF:

DESCRIPTION: A fragment of a very corroded bracelet of waisted section.

DIMENSIONS AND WEIGHT:

section: 7 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 59.066%; Sn 3.644%; Pb 15.245%; As 1.532%; Fe 0.362%;
Bi 0.019%
Total 79.868%

METALLOGRAPHIC STRUCTURE:

The cross section shows the decorated area. The micro-structure of the section is uniform α-dendrites in very corroded (α+δ) eutectoid. There is no evidence of working or heat treatment.

COMMENTS:

The bracelet was cast.

CATALOGUE ENTRY

SITE: BANYANG
NAKHON PATHOM PROVINCE

AREA: Pit:

LAB NO: 1902A

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 394-402

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A bronze bead of pendant form.

DIMENSIONS AND WEIGHT:

width: 4.075 mm
height: 7.86 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 77.57-88.91%; Sn 7.57-9.08%; Pb 1.61-10.842%;
S 0.007-0.078%; As 0.967-1.098%; Fe 0.116-0.133%;
Sb 0.048-0.174%; Ni 0.052 0.117%; Ag 0.068-0.174%;
Au 0.124-0.131%

METALLOGRAPHIC STRUCTURE:

Cored dendrites in a background of eutectoid with black lead globules. There are also a lot of casting cavities.

COMMENTS:

The object was cast and not otherwise worked.

CATALOGUE ENTRY

SITE: BANYANG
NAKHOM PATHOM PROVINCE

LAB NO: 1902C

EXCAVATION NO:

MUSEUM NO:

PERIOD: Uncertain

PRESENT LOCATION: AD/B

EXCAVATION REF:

AREA: Pit:

Layer:

Depth:

Plate Nos: The same as 1902D for the photograph of the object and Pl. 403-406.

Fig Nos:

DESCRIPTION: A fragment of a rectangular section ring.

DIMENSIONS AND WEIGHT:

thickness: 1.5-2 mm.

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 51.35-87.62%; Sn 7.31-12.26%; Pb 0.084-52.07%;
S 0.024-0.130%; As 0.180-0.486%; Fe 0.128-0.165%;
Sb 0.012-0.554%; Ni 0.073%; Ag 0.066-0.428%;
Au 0.08-0.287%; Zn 0.102%

ICP: Cu 76.410%; Sn 9.65%; Pb 8.725%; As 0.499%; Sb 0.163%;
Fe 0.340%; Ag 0.098%; Ni 0.036%; Co 0.008%; Bi 0.034%;
Total 95.963%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in the (α+δ) eutectoid. Black dots of lead distributed all over the specimen. The dendrites are small. There are some gray-blue inclusions of cuprite.

COMMENTS:

The object was cast and fairly rapidly cooled. There is a significant lead content.

CATALOGUE ENTRY

SITE: BANYANG
NAKHON PATHOM PROVINCE

AREA: Pit:

LAB NO: 1902D

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 403, 407 and 408

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a ring.

DIMENSIONS AND WEIGHT:
thickness: 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA:	Sn 7.57-11.78%	Cu 84.87-90.44%	Pb 0.29-0.49%
	S 0.004-0.09%	As 0.19-0.4%	Fe 0.12-0.21%
	Sb 0.008%	Ni 0.030%	Ag 0.08%
	Au 0.24-0.46%		

Metallic inclusion (copper)
Lead globules

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in the (α+δ) eutectoid. Black lead globules distributed all over the specimen. Metallic inclusions of pink colour (copper) and blue-gray inclusions of cuprite are also present.

COMMENTS:

The object was cast and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: BANYANG
NAKHON PATHOM PROVINCE

AREA: Pit:

Layer:

Depth:

LAB NO: 1902G

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 409

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of the rim of a container, very corroded.

DIMENSIONS AND WEIGHT:

thickness (section): 2-4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 65.435%; Sn 8.154%; Fe 0.104%
Total 73.694%

METALLOGRAPHIC STRUCTURE:

COMMENTS·

CATALOGUE ENTRY

SITE: KHOK PHON YANG, AMPHOE WARITCHAPHUM, SAKON NAKHON PROVINCE

AREA: Pit:

Layer:

Depth:

LAB NO: 1903

EXCAVATION NO:

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of one of several fused bracelets, corroded very badly. The section is D-shaped.

DIMENSIONS AND WEIGHT:

section: 3x2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 52.419%

ICP: Cu 56.978%; Sn 14.932%; Pb 0.200%; As 0.403%; Sb 0.150%; Fe 0.271%; Ag 0.013%; Ni 0.037%; Co 0.011%
Total 72.995%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

No metallographic examination. The object was probably cast.

SITE: NAI TONG SOON, TAM BON: DON TAN, AMPHOE DON TAN NAKHON PHANOM; Lat.16°19'05"N, Long.104°56'23"E.

CATALOGUE ENTRY

SITE: NAI TONG SOON

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1904A

EXCAVATION NO: 3 นพ.1

MUSEUM NO:

Plate Nos: 410-415

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of decorated bracelet with black patina. The bracelet is decorated only on the outer side.

DIMENSIONS AND WEIGHT:

section: 18 x 2.4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 75.52-76.72%; Sn 23.27-24.015%; Fe 0.39-0.65%
Square black inclusion: Cu 44.92%; Sn 9.899%; As 2.846%; Fe 26.392%

ICP: Cu 76.575%; Sn 23.39%; Pb 0.126%; As 0.121%; Sb 0.164% Fe 2.22%; Ag 0.008%; Ni 0.026%; Co 0.024%; Bi 0.024%
Total 102.679%

METALLOGRAPHIC STRUCTURE:

The structure is of β'-martensite (banded martensite or features of long thin markings) in large grains of β_1-phase. From the result of EPMA and ICP, the iron content in this sample is rather high. There are iron inclusions in the sample.

COMMENTS:

The object was cast and heated up to the β-region of around 700°C and quenched in water. The decoration is cut in. The patina of very dark green to black colour is characteristic of high tin bronze in the β' martensite region.

CATALOGUE ENTRY

SITE: NAI TONG SOON

AREA: Pit: survey

LAB NO: 1904B

Layer:

Depth:

EXCAVATION NO: 4 นพ.1

MUSEUM NO:

Plate Nos: 416-420

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a D-shaped bracelet with olive green patina on the surface.

DIMENSIONS AND WEIGHT:

thickness (section): 0.2 x 0.8 cm D

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: martensite background
Cu 77.75-82.448%; Sn 19.114-23.463%; S 0.315%;
Fe 0.198-0.232%; Sb 0.573%

ICP: Cu 78.110%; Sn 21.67%; Pb 0.114%; As 0.193%; Sb 0.157%
Fe 0.132%; Ag 0.009%; Ni 0.016%; Co 0.004%; Bi 0.018%
Total 100.423%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase on a background of acicular coarse compact β-martensite.

COMMENTS:

The object has been cast and slightly hot-worked. It was then heated up to the $(\alpha+\beta)$ region 798^{o}-586^{o}C) and quenched in water.

CATALOGUE ENTRY

SITE: NAI TONG SOON

AREA: Pit: survey

Layer:

Depth:

LAB NO: 1904C

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 421-424

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a D-shaped bracelet with dark green patina on surface and vertical line decoration on the surface.

DIMENSIONS AND WEIGHT:

section: 6.5 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 79.442%; Sn 22.32%; Pb 0.144%; As 0.172%; Sb 0.194%; Fe 0.991%; Ag 0.009%; Ni 0.022%; Co 0.012%; Bi 0.029%
Total 103.335%

METALLOGRAPHIC STRUCTURE:

Very small α-phase regions (some twinned) on a background of very compact needles of β-martensite. The amount of α-phase is also small.

COMMENTS:
The object must be cast and heat-treated and quenched from around 700°C in water. The decoration was added by cutting.

CATALOGUE ENTRY

SITE: BAN NA-AN, AMPHOE MUANG, LOEI PROVINCE, Lat.17°27'05"N, Long.101°44'10"E.

AREA: Pit:

Layer:

Depth:

LAB NO: 1905A

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 425-435

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: Khon Kaen National Museum

EXCAVATION REF:

DESCRIPTION: A hollow axe.

DIMENSIONS AND WEIGHT:
height: 4.6 cm
width: 4.5 cm
thickness: 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
AA: Cu 79.150%
ICP: Cu 101.129%; Sn 7.626%; Pb 0.127%; As 0.193:
Sb 0.149%; Fe 0.108%; Ag 0.097%; Ni 0.028%;
Co 0.010%; Bi 0.030%
Total 109.497%

METALLOGRAPHIC STRUCTURE:
Cutting edge: The structure revealed equiaxial grains with bent twin bands and heavy strain lines. This suggests that the axe was cast then cold worked, annealed, and then cold worked again. The heavy strain lines and bent twin bands are evidence of cold working at the final stage of manufacture of the cutting edge. Another cause of such strain lines may be due to the stress from the cutting action when the axe was used.
Side of the axe: The structure revealed was that of cast low-tin bronze. There was no evidence of dendrites. In a small area there were twin bands in equiaxial grains. The structure can be described as that the object was cast and slightly worked and then annealed.

COMMENTS:
The overall technology of the axe was firstly casting into shape. The cutting edge was then hammered down for the process of sharpening, then the axe was annealed but only the cutting edge was hammered down again.

CATALOGUE ENTRY

SITE: BAN NA-AN, AMPHOE MUANG, LOEI PROVINCE, Lat.17°27'05"N, Long. 101°-4'10"E.

AREA: Pit: survey

LAB NO: 1905 B

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 436-438

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: NEAU/KK

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of D-shaped section. The object has decoration as shown in the plate. The rim of the bracelet is of castellated form.

DIMENSIONS AND WEIGHT:

section: 5.5 x 4 mm D

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 80.218%; Sn 21.19%; Pb 0.169%; As 0.188%; Sb 0.170%; Fe 0.087%; Ag 0.029%; Ni 0.030%; Co 0.004%; Bi 0.007%
Total 102.092%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase on a background of acicular coarse compact β-martensite.

COMMENTS:

The bracelet was cast and slightly hot-worked. It was then heated up to the (α+δ) region (798°-586°C) and quenched into water. The decoration was added by cutting.

CATALOGUE ENTRY

SITE: NAI TANG; TAMBON NAI MUANG; AMPHOE MUANG, ROI ET PROVINCE; Lat 16°39'40"N; Long 103°39'19"E.

AREA: Pit: survey

LAB NO: 1906A

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 439-443

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A circular section bracelet with helical ribbed decoration. The bracelet is hollow with a core.

DIMENSIONS AND WEIGHT:

diameter (section): 1.3 cm
thickness of metal: approx. 1.0-1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 92.391%

ICP: Cu 104.509%; Sn 6.506%; Pb 1.094%; As 0.181%; Sb 0.205%; Fe 0.061%; Ag 0.088%; Ni 0.028%; Co 0.006%; Bi 0.017%
Total 112.695%

METALLOGRAPHIC STRUCTURE:

Dendritic structure of α-phase in ($\alpha+\delta$) eutectoid. There are some casting cavities, lead particles, and gray-blue inclusions of cuprite.

COMMENTS:

The object was lost wax hollow cast with a core still remaining in place. There is no evidence of working or heat treating.

CATALOGUE ENTRY

SITE: NAI TANG; TAMBON NAI MUANG, AMPHOE MUANG, ROI ET PROVINCE, Lat 16°39'40"N; Long 103°39'19"E

AREA: Pit:

Layer:

Depth:

LAB NO: 1906B

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 444-448

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Fragment of a circular section bracelet.

DIMENSIONS AND WEIGHT:

diameter (section): 0.4 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 90.33-93.12%; Sn 7.39 10.28%
Metallic inclusion

ICP: Cu 85.755%; Sn 11.99%; Pb 1.322%; As 0.134%; Sb 0.165%;
Fe 0.038%; Ag 0.129%; Ni 0.022%; Co 0.006%; Bi 0.019%
Total 00.58%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well developed form in the (α+δ) eutectoid. The dendrites radiate from the centre of the section. There are large casting cavities. Metallic inclusions also appear in the specimen. There are some marks or lines in some dendrites. These marks may be strain or slip lines.

COMMENTS:

The objects were cast and slow-cooled.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1909

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 449-451

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Khon Kaen Museum

EXCAVATION REF:

DESCRIPTION: A hollow cast bracelet with surface decoration and bosses. Ban Chiang style.

DIMENSIONS AND WEIGHT:

diameter of bracelet: approx. 10-12 cm.
thickness (section): " 2-3 mm.

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

α-dendrites in a corroded eutectoid. The α-dendrites are of a well developed form.

COMMENTS:

From the structure, the object was lost wax hollow cast, and the core material was removed. The engraved type of decoration was formed as part of the casting.

CATALOGUE ENTRY

SITE: Unknown AREA: Pit:

LAB NO: 1911 Layer:

Depth:

EXCAVATION NO:

MUSEUM NO: 240/2515/31/24 Plate Nos: 452-455

PERIOD: Uncertain, may be Ban Chiang Culture.
Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: An incomplete circular section bracelet, badly corroded.

DIMENSIONS AND WEIGHT:

diameter (outer, bracelet):	6.5 cm
diameter (inner, bracelet):	5.5 cm
thickness:	0.5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: background: Cu 95.92-97.94%; Sn 3.88-5.512%; Fe trace
Sulphide inclusion: Cu 80.80-81.09%; Sn 0.027-0.762%;
S 19.16-19.813%; Fe and Ag traces

ICP: Cu (instrument failure, cannot estimate); Sn 6.37%;
Pb 0.151%; As 0.053%; Sb 0.132%; Fe 0.018%; Ag 0.158%;
Ni 0.009%; Co 0.005%; Bi 0.012%;
Total 6.908%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in corroded (α+δ) eutectoid with a lot of casting cavities. Sulphide inclusions of gray colour also appear very clearly in the specimen.

COMMENTS:

The object was cast and fairly rapidly cooled. Sulphide inclusions can be seen very clearly in Pl.455 (the analysis obtained by using EPMA).

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

Layer:

Depth:

LAB NO: 1912A

EXCAVATION NO:

MUSEUM NO: 47

Plate Nos: 456-459

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet, rectangular section with convex outer surface.

DIMENSIONS AND WEIGHT:

section: 2 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.153%; Sn 12.57%; Pb 7.332%; As 1.562%;
Sb 0.359%; Fe 0.113%; Ag 0.311%; Ni 0.080%;
Co 0.02%; Bi 0.519%;
Total 105.019%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in ($\alpha+\delta$) eutectoid with lead globules distributed all over the sample. There are a lot of large casting cavities.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1912B

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 460-462

PERIOD: Uncertain, may be Ban Chiang Culture

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet.

DIMENSIONS AND WEIGHT:

diameter (section): 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 97.85-99.59%; Sn 0.614-2.380%

ICP: Cu 91.924%; Sn 2.22%; Pb 0.660%; As 0.127%; Sb 0.132%; Fe 0.029%; Ag 0.025%; Ni 0.017%; Co 0.004%; Bi 0.011%;
Total 95.149%

METALLOGRAPHIC STRUCTURE:

The structure consists of large grains of α-phase. There is no evdience of dendrites or twinning.

COMMENTS:
The object was cast then annealed.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1912C

Layer:

Depth:

EXCAVATION NO.

MUSEUM NO: 47

Plate Nos: 463-464

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a circular solid section bracelet with catch at end.

DIMENSIONS AND WEIGHT:

diameter (section): 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 93.280%; Sn 2.07%; Pb 0.363%; As 0.128%; Sb 0.129%; Fe 0.055%; Ag 0.025%; Ni 0.020%; Co 0.005%; Bi 0.0072%;
Total 96.082%

METALLOGRAPHIC STRUCTURE:

The structure consists of large grains of α-phase. There is no clear evidence of dendrites. There are large casting cavities.

COMMENTS:

The object was cast then annealed.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1912 E

Layer:

Depth:

EXCAVATION NO: 47

MUSEUM NO:

Plate Nos: 465-466

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of rectangular section bracelet.

DIMENSIONS AND WEIGHT:

diameter (outer, bracelet): 6 cm
diameter (inner, bracelet): 4.7 cm
section: 7 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.165%; Sn 8.67%; Pb 0.392%; As 0.203%; Sb 0.147%; Fe 0.048%; Ag 0.023%; Ni 0.023%; Co 0.005%; Bi 0.008%;
Total 101.68%

METALLOGRAPHIC STRUCTURE:

α-dendrites in the $(\alpha+\delta)$ eutectoid. There are black globules distributed all over the sample, the casting cavities are large.

COMMENTS:

The object was cast without further working or heat treating.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

Layer:

Depth:

LAB NO: 1912 F

EXCAVATION NO: 47

MUSEUM NO:

Plate Nos: 467-469

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a D-shape solid section bracelet, very badly corroded.

DIMENSIONS AND WEIGHT:

section: 15 x 7 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 88.15-98.85%; Sn 7.07-7.69%; Pb 0.012-0.18%; S 0.01-0.08%; As 0.038%; Fe 0.37-0.182%; Sb 0.09-0.25%; Ni 0.002 0.09%; Ag 0.004-0.23%; Au 0.09-0.25%; Zn 0.03-0.63%

METALLOGRAPHIC STRUCTURE:

Dendritic structure of α-phase in corroded (α+δ) eutectoid. The dendrites radiate from the centre of the specimen.

COMMENTS:

The object was cast and slowly cooled.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

Layer:

Depth:

LAB NO: 1912 G

EXCAVATION NO: 47

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain, may be Ban Chiang Culture

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a circular solid section bracelet.

DIMENSIONS AND WEIGHT:

diameter (section): 6 mm ○

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.301%; Sn 4.37%; Pb 0.772%; As 0.201%; Sb 0.144%; Fe 0.017%; Ag 0.035%; Ni 0.021%; Co 0.004%; Bi 0.023%;
Total 97.878%

METALLOGRAPHIC STRUCTURE·

COMMENTS:

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1912 H

Layer:

Depth:

EXCAVATION NO: 47

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A very corroded D-shaped solid section bracelet.

DIMENSIONS AND WEIGHT:

section: 11 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Dendrite: Cu 72.75-88.69%; Sn 10.28-12.79%; Pb 2.550%;
As 0.67-1.49%; Ag 0.508%;
Lead particles

METALLOGRAPHIC STRUCTURE:

COMMENTS·

A cast leaded bronze.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1913 A

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO: 51

Plate Nos: 470-476

PERIOD: Uncertain, may be Ban Chiang Culture

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION:

A fragment of a bracelet, ribbed section.

DIMENSIONS AND WEIGHT:

thickness(section): 2 x 8 mm
width (bracelet): 2.4 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

α-phase structure with heavy strain lines in an unidentified background (due to corrosion).

COMMENTS:

The object seems to be cast and annealed then cold worked.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

Layer:

Depth:

LAB NO: 1913 B

EXCAVATION NO:

MUSEUM NO: 51

Plate Nos: 477-480

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

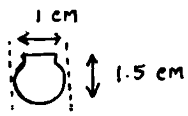
EXCAVATION REF:

DESCRIPTION:

A fragment of solid section bracelet with spherical protrusions.

DIMENSIONS AND WEIGHT:

width (section): 1 cm
height (section): 1.5 cm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.394%; Sn 5.77%; Pb 0.225%; As 0.159%; Sb 0.144%; Fe 0.086%; Ag 0.023%; Ni 0.022%; Co 0.004%; Bi 0.017%
Total 98.844%

METALLOGRAPHIC STRUCTURE:
α-dendrites in (α+δ) eutectoid. The eutectoid is corroded completely. There are also gray-blue inclusions (cuprite) found mixed together with corroded eutectoid in some corroded parts of the eutectoid. Redeposited copper (pink globules) surrounded by cuprite (gray-blue). Some of redeposited copper is free from cuprite. Lead globules distributed all over the specimen. Shrinkage cavities are also found throughout.

COMMENTS:

The bracelet was cast without further working or heat treating.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1914 A

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 481

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a D-shaped solid section bracelet.

DIMENSIONS AND WEIGHT:

section: 5 x 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 63.36%; Sn 7.881%; Pb 0.122%; As 0.135%; Sb 0.134%; Fe 0.279%; Ag 0.038%; Ni 0.013%; Co 0.005%; Bi 0.005%;
Total 71.970%

AA: Cu 50.539%

METALLOGRAPHIC STRUCTURE:

The object corroded very badly. There is some uncorroded α-phase appearing in the completely corroded background of another phase. There are strain lines on the α-phase in some areas of the specimen. Nearly all of the α-phase has redeposited copper on the boundary.

COMMENTS:

Cast and annealed.

CATALOGUE ENTRY

SITE: Unknown

AREA: Pit:

LAB NO: 1914 B

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 482

PERIOD: Uncertain, may be Ban Chiang Culture.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: Fragment of a circular section solid bracelet.

DIMENSIONS AND WEIGHT:

diameter (section): 1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 69.583%; Sn 8.291%; Pb 0.136%; As 0.084%; Sb 0.138%; Fe 0.226%; Ag 0.020%; Ni 0.017%; Co 0.007%;
Total 78.502%

AA: Cu 62.263%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Almost certainly cast and annealed.

CATALOGUE ENTRY

SITE: THE ONGBAH CAVE
KANCHANABURI PROVINCE

AREA: Pit:

Layer:

Depth:

LAB NO: 1915 A

EXCAVATION NO:

MUSEUM NO: 35/2517/242

Plate Nos: 483-487

PERIOD: Dong Song

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a drum from Ong Bah Cave. The patina on the surface is black.

DIMENSIONS AND WEIGHT:
thickness: approx 1.2-1.3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Sn 4.6-6.6%; Cu 93.63-95.78%

ICP: Cu 85.896%; Sn 8.298%; Pb 4.542%; As 0.243%;
Sb 0.142%; Fe 0.049%; Ag 0.064%; Ni 0.056%;
Co 0.007%; Bi 0.218%
Total 99.515%

METALLOGRAPHIC STRUCTURE·

The section was very corroded. Only a very small area of α-dendrite remains in nearly completely corroded eutectoid. There are some black lead globules in the specimen.

COMMENTS·

The object was cast only, without further working or heat treatment.

CATALOGUE ENTRY

SITE: THE ONGBAH CAVE
KANCHANABURI PROVINCE

AREA: Pit:

Layer:

Depth:

LAB NO: 1915 B

EXCAVATION NO:

MUSEUM NO: 35/2517/242

Plate Nos: 483, 484 and 488-490

PERIOD: Dong Song

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of drum from Ong Bah Cave.

DIMENSIONS AND WEIGHT:

thickness: approx. 1.2 mm.

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 83.917%; Sn 7.73%; Pb 4.588%; As 0.220%;
Sb 0.140%; Fe 0.063%; Ag 0.070%; Ni 0.051%;
Co 0.005%; Bi 0.230%
Total 97.014%

METALLOGRAPHIC STRUCTURE:

α-dendrites in a nearly completely corroded $(\alpha+\delta)$ eutectoid. There were a lot of casting cavities and lead globules throughout the specimen.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: THE ONGBAH CAVE
KANCHANABURI PROVINCE

AREA: Pit:

Layer:

Depth:

LAB NO: 1915 C

EXCAVATION NO:

MUSEUM NO: 35/2517/242

Plate Nos: 483 and 484

PERIOD: Dong Song

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of the handle of a drum from Ong Bah Cave. The patina on the surface is black.

DIMENSIONS AND WEIGHT:

thickness: ~1.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 76.651%; Sn 8.387%; Pb 6.523%; As 0.195%;
Sb 0.155%; Fe 0.080%; Ag 0.213%; Ni 0.056%;
Co 0.008%; Bi 0.223%
Total 92.491%

AA: Cu 62.814%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

See 1915A and 1915B.

CATALOGUE ENTRY

SITE: KOK MAKAMTAO, Ratchaburi Province
Lat.13°39'4"N; Long.100°03'20"E

AREA: Pit: AII NWQ

LAB NO: 1302

Layer: (4)

Depth: 60-66 cm

EXCAVATION NO: 41, SF #9

MUSEUM NO:

Plate Nos: 492

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A complete circular section ring, very corroded.

DIMENSIONS AND WEIGHT:

diameter (outer): 1.9 cm
diameter (inner): 1.5 cm
diameter (section): 0.2 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 88.157%; Sn 10.596%; Pb 2.502%; As 0.285%;
Sb 0.029%; Fe 1.283%; Ag 0.475%; Ni 0.023%;
Bi 0.074%;
Total 103.423%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: KOK PLUP

AREA: Pit: L' 1' NEQ

LAB NO: 1201

Layer: 7 / (8)

Depth: 112 cm

EXCAVATION NO: 100, SF #9

MUSEUM NO:

Plate Nos: 491

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of an unidentified object, very corroded.

DIMENSIONS AND WEIGHT:

thickness: 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 99.322%; Sn 7.776%; Fe 0.080%; Ag 0.204%
Total 107.382%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: KOK MAKAMTAO, Ratchaburi Province
Lat.13°39'4"N;Long.100°03'20"E. AREA: Pit: A II WWQ

LAB NO: 1305 Layer: (5)

EXCAVATION NO: 62, SF No. 19 Depth: 60-66 cm

MUSEUM NO: Plate Nos: 493

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, very corroded.

DIMENSIONS AND WEIGHT:

diameter (outer): 6.5 cm
diameter (inner): 6.1 cm
thickness: 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 73.873%; Sn 10.519%; Pb 16.130%; As 0.422%;
Sb 0.016%; Fe 0.561%; Ag 0.088%; Ni 0.019%;
Bi 0.073%;
Total 101.704%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NOEN KLONG BAMRUNG, Lop Buri Province, Amphoe Chai Badan

AREA: Pit: from survey

LAB NO: 1402

Layer:

Depth:

EXCAVATION NO: SF No. 171

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A small fragment of a bracelet.

DIMENSIONS AND WEIGHT:
thickness (section): 1-1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 88.319%; Sn 7.227%; As 0.049%; Sb 0.019%;
Fe 0.137%; Ag 0.534%; Ni 0.043%;
Total 96.329%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NOEN KLONG BAMRUNG
Lopburi Province; Amphoe Chai Badan

AREA: Pit: AI SEQ

Layer: (3)

LAB NO: 1404

Depth:

EXCAVATION NO: SF No.35

MUSEUM NO:

Plate Nos: 494

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: Fragment of corroded metal.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.729%; Sn 2.051%; As 0.266%; Sb 0.017%;
Fe 0.088%; Ag 0.246%; Ni 0.002%; Zn 0.074%;
Total 95.473%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

SITE 4. NON NOK THA

PHU WIANG DISTRICT, KHON KAEN PROVINCE

Lat.16°47'57"N; Long.102°18'17"E

CATALOGUE ENTRY

SITE:	NON NOK THA	AREA:	Pit:	E 3 B.31
LAB NO:	15 001		Layer:	(17)
EXCAVATION NO:	NP551, NP7, No.1		Depth:	
MUSEUM NO:		Plate Nos:		495
PERIOD:	MP approx. 1100 BC	Fig Nos:		
PRESENT LOCATION:	HU/USA			
EXCAVATION REF:				

DESCRIPTION: A complete bracelet of D-shaped section, solid cast. Heavy corrosion layers.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 5.3 cm
section: 9 x 4 mm

D

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.279%; Sn 9.710%; Pb 0.717%; As 0.097%; Sb 0.151%; Fe 0.138%; Ag 0.018%; Ni 0.013%; Co 0.005%; Bi 0.013%; Total 94.141%

METALLOGRAPHIC STRUCTURE:

COMMENTS:
No metallography was carried out, but the bracelet was cast, with a low lead content (less than 1%). The structure should be the same as for object 15013.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3 B.31

Layer: (17)

Depth:

LAB NO: 15002

EXCAVATION NO: NP551, NP7, No.2

MUSEUM NO:

Plate Nos:

Fig Nos:

PERIOD: MP, approx. 1100 BC

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 5.7 cm D
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 80.595%; Sn 8.930%; Pb 0.474%; As 0.081%; Sb 0.134%; Fe 0.074%; Ag 0.015%; Ni 0.012%; Co 0.003%; Bi 0.007%

Total 90.335%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

Layer: (17)

Depth:

LAB NO: 15003

EXCAVATION NO: NP551, NP7, No.3

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 5.7 cm
section: 9 x 4 mm D

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.114%; Sn 8.120%; Pb 0.520%; As 0.088%; Sb 0.130%;
Fe 0.100%; Ag 0.015%; Ni 0.011%; Co 0.0032%; Bi 0.006%;
Total 90.107%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

Layer: (17)

Depth:

LAB NO: 15004

EXCAVATION NO: NP551, NP7, No.4

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:
bracelet: diameter (inner): 6 cm D
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.187%; Sn 10.98%; Pb 1.069%; As 0.115%; Sb 0.148%;
Fe 0.070%; Ag 0.022%; Ni 0.010%; Co 0.003%; Bi 0.013%;
Total 95.43%

METALLOGRAPHIC STRUCTURE:

COMMENTS:
As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

Layer: (17)

Depth:

LAB NO: 15005

EXCAVATION NO: NP551, NP7, No.5

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6 cm
section: 9x4 mm

D

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.997%; Sn 10.26%; Pb 1.063%; As 0.12%; Sb 0.148%; Fe 0.039%; Ag 0.020%; Ni 0.012%; Co 0.003%; Bi 0.019%;
Total 93.681%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA — AREA: Pit: E3, B31

LAB NO: 15006 — Layer: (17)

Depth:

EXCAVATION NO: NP551, NP7, No.6

MUSEUM NO: — Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

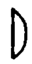
PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6.2 cm
section: 9 x 4 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.093%; Sn 10.90%; Pb 1.226%; As 0.106%; Sb 0.148%;
Fe 0.100%; Ag 0.035%; Ni 0.01%; Co 0.002%; Bi 0.018%;
Total 95.638%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The lead content is greater than 1%. The microstructure should be similar to 15001, but the amount of lead particles will increase. The dendritics should still be seen clearly.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

LAB NO: 15007

Layer: (17)

Depth:

EXCAVATION NO: NP551, NP7

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:
bracelet: diameter (inner): 6 cm
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.694%; Sn 10.67%; Pb 1.054%; As 0.130%; Sb 0.151%;
Fe 0.057%; Ag 0.019%; Ni 0.013%; Co 0.004%; Bi 0.032%;
Total 93.824%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

Layer:

Depth:

LAB NO: 15008

EXCAVATION NO: NP551, NP7, No.8

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION:

A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6.5 cm

section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 78.268%; Sn 10.12%; Pb 0.972%; As 0.109%; Fe 0.086%:
Ag 0.027%; Ni 0.012%; Co 0.004%; Bi 0.011%;
Total 89.768%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E3, B31

Layer: (17)

Depth:

LAB NO: 15009

EXCAVATION NO: NP551, NP7, No.9

MUSEUM NO:

Plate Nos: 496

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION:
A complete bracelet of D-shaped section, solidcast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6.7 cm D
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 72.543%; Sn 10.069%; Pb 1.061%; As 0.163%; Sb 0.180%; Fe 0.073%; Ag 0.046%; Ni 0.019%; Co 0.009%;
Total 84.163%

AA: Cu 76.547%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B.31, L1

Layer: (7)

Depth:

LAB NO: 15010

EXCAVATION NO: NP551/1, NP7

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 5.4 cm D
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 80.642%; Sn 10.49%; Pb 0.998%; As 0.094%; Sb 0.150%;
Fe 0.026%; Ag 0.023%; Ni 0.012%; Co 0.003%; Bi 0.006%;
Total 92.444%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B.31 L1

Layer: (17)

Depth:

LAB NO: 15011

EXCAVATION NO: NP551/2, NP7

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner) 5.5 cm
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 88.460%; Sn 10.75%; Pb 0.837%; As 0.107%; Sb 0.143%; Fe 0.075%; Ag 0.015%; Ni 0.011%; Co 0.003%; Bi 0.012%;
Total 100.413%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B.31 RIGHT

Layer: (17)

Depth:

LAB NO: 15012

EXCAVATION NO: NP551/3; RE CAT.NP 1529

MUSEUM NO:

Plate Nos: 497 and 498

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of circular section, with 4 bosses. It is solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6 cm
thickness: 0.3 cm
thickness (decoration): 0.5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 77.379%; Sn 8.59%; Pb 4.479%; As 0.147%; Sb 0.142%; Fe 0.057%; Ag 0.071%; Ni 0.020%; Co 0.005%; Bi 0.027%;
Total 90.917%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The lead content is greater than 1%. The microstructure should be similar to 15017 due to the similarity of the lead content.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B31 L15

LAB NO: 15013

Layer: (17)

Depth:

EXCAVATION NO: NP551/4

MUSEUM NO:

Plate Nos: 499-509

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Four fragments of D-shaped section bracelet, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 7 cm D
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.4%; Sn 10.38%; Pb 0.882%; As 0.122%; Sb 0.154%;
Fe 0.051%; Ag 0.023%; Ni 0.012%; Co 0.003%; Bi 0.013%;
Total 95.04%

METALLOGRAPHIC STRUCTURE:

α-dendrites in the eutectoid. The dendrites are of well developed form, and large. The amount of lead is less than 1% and the lead globules do not appear very clearly.

COMMENTS:

The object was cast and slow cooled.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B.31 L2

Layer: (17)

Depth:

LAB NO: 15014

EXCAVATION NO: NP551/5, NP7

MUSEUM NO:

Plate Nos:

PERIOD: MP approx 1100 BC

Fig Nos:

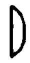
PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 5.4 cm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 93.623%; Sn 11.60%; Pb 0.97%; As 0.134%; Sb 0.152%;
Fe 0.089%; Ag 0.017%; Ni 0.011%; Co 0.004%; Bi 0.018%;
Total 106.618%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15013.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: B.31 L14

Layer: (17)

Depth:

LAB NO: 15015

EXCAVATION NO: NP551/6, NP7

MUSEUM NO:

Plate Nos:

PERIOD: MP approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete bracelet of D-shaped section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6.8 cm
section: 9 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.840%; Sn 11. 33%; Pb 1.037%; As 0.127%; Sb 0.154%; Fe 0.057%; Ag 0.020%; Ni 0.011%; Co 0.004%; Bi 0.011%;
Total 94.591%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15001 and 15013.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4H

Layer: 6A

Depth:

LAB NO: 15016

EXCAVATION NO: NNT 526, 1140

MUSEUM NO:

Plate Nos: 510

PERIOD: approx. 500 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A complete bracelet of circular section, solid cast.

DIMENSIONS AND WEIGHT:

bracelet: diameter (inner): 6.3 cm
(outer): 7.2 cm

section: 4 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP:	Cu 82.374%;	Sn 2.237%;	Pb 12.287%;	As 0.561%;	Sb 0.548%;
	Fe 0.016%;	Ag 0.378%;	Ni 0.080%;	Co 0.012%;	Bi 0.004%;
	Total 88.497%				

AA: Cu 79.124%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15023 (due to the similarity in lead content).

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (19)

Depth:

LAB NO: 15017 A & B

EXCAVATION NO: NP 553

MUSEUM NO:

Plate Nos: 511-518

PERIOD: Approx. 1100-1800 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Pair of bracelets. One of these bracelets (B) was in 2 pieces. The sample was taken from B.

DIMENSIONS AND WEIGHT:

bracelet: diameter (outer): 6.2 cm
(inner): 5.5 cm
section: 4.5 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.359%; Sn 5.110%; Pb 6.237%; As 0.151%; Sb 0.150%; Fe 0.071%; Ag 0.081%; Ni 0.041%; Co 0.010%; Bi 0.034%;
Total 94.238%

EPMA: Cu 94.604-98.517%; Sn 1.973-10.175%; Pb 0.339-0.574%; S 0.04-0.05%; As 0.002-0.127%; Fe 0.136-0.149%; Sb 0.175-0.297%; Ni 0.014-0.10%; Ag 0.008-0.146%; Au 0.115-0.159%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small balck lead globules.

COMMENTS:

The object was cast, and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2F

LAB NO: 15018

Layer: (6)/(7)

Depth:

EXCAVATION NO: NNT 307, /498A

MUSEUM NO:

Plate Nos: 519 and 520

PERIOD: Approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A projectile point. Very badly corroded and broken into 3 pieces.

DIMENSIONS AND WEIGHT:

height: 3.7 cm
width: 2.5 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 38.885%; Sn 4.930%; Fe 0.478%
Total 44.294%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C.7

LAB NO: 15019

Layer: (9) 27-1-66
See NB V, 8

EXCAVATION NO: /1069D, NP 7

Depth: 138 cm < E. Baulk
8 cm < S. Baulk
absolute depth=53 cm

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 3 fragments of corroded bronze rectangular section bracelet. One piece is the catch of the bracelet.

DIMENSIONS AND WEIGHT:

bracelet (with catch), width: 0.4 cm
thickness: approx. 0.2-0.25 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.20%; Sn 5.619%; Pb 16.801%; As 0.363%; Sb 0.199%;
Fe 0.033%; Ag 0.227%;
Total 104.474%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15023.

CATALOGUE ENTRY

SITE:	NON NOK THA	AREA:	Pit:
LAB NO:	15021		Layer:
			Depth:
EXCAVATION NO:	NNT 517, NP7, 1594		
MUSEUM NO:		Plate Nos:	521-524
PERIOD:	Uncertain		
		Fig Nos:	
PRESENT LOCATION:	HU/USA		
EXCAVATION REF:			

DESCRIPTION: 5 fragments of bronze, very heavily corroded. Fragment E was used in both metallography and chemical analysis.

DIMENSIONS AND WEIGHT:

weight:	A:	3.42 gm		
	B:	1.26 gm	D:	1.30 gm
	C:	1.15 gm	E:	1.44 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 91.506-92.302%; Sn 6.902-7.695%; Pb 0.004%; S 0.016-0.044%; As 0.015%; Fe 0.121-0.147%; Sb 0.387%; Ni 0.141%; Ag 0.005-0.135%; Au 0.079-0.176%

METALLOGRAPHIC STRUCTURE:

Only α-phase appears. There is no clear evidence of working.

COMMENTS:

The object was cast and annealed.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4H

LAB NO: 15022

Layer: 5U

Depth:

EXCAVATION NO: NNT 536

MUSEUM NO:

Plate Nos: 525-530

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a blade? The small section was taken from the corner. The shape of the section was triangular.

DIMENSIONS AND WEIGHT:

blade: length: 4.7 cm
width: 1.7 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 86.042-88.653%; Sn 10.997-13.440%; Pb 0.002-0.317%; S 0.027-0.062%; As 0.664-0.978%; Fe 0.059-0.177%; Sb 0.072-0.314%; Ni 0.053-0.077%; Ag 0.034-0.273%; Au 0.133-0.514%

ICP: Cu 81.846%; Sn 12.493%; Pb 0.891%; As 0.952%; Sb 0.188%; Fe 0.046%; Ag 0.187%; Ni 0.034%; Co 0.011%; Bi 0.065%
Total 96.713%

AA: Cu 81.776%

METALLOGRAPHIC STRUCTURE:

The structure consisted of equiaxial grains with twin bands. In some areas there are still traces of dendrites and eutectoid in the interdendritic areas. There are casting cavities and gray-blue inclusions.

COMMENTS:

The object was cast then worked and annealed not quite long enough to remove the dendritic structure. It is possibly the cutting edge of a socketed axe.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4E

Layer: (5) Top 10 cm.

Depth:

LAB NO: 15023

EXCAVATION NO: NNT 134

MUSEUM NO:

Plate Nos: 531-537

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, solid cast.

DIMENSIONS AND WEIGHT:

section: 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 78.644%; Sn 11.349%; Pb 13.372%; As 0.246%; Sb 0.232%; Fe 0.025%; Ag 0.160%; Ni 0.028%; Co 0.008%; Bi 0.015%; Total 104.079%

AA: Cu 78.585%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules. Gray-blue inclusions are also present.

COMMENTS:

The object was cast, and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C-3
Layer: (11) Fill
Depth:

LAB NO: 15032

EXCAVATION NO: /1552D, NP7, 12-2-66

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of bracelet, very corroded with malachite, bronze disease and soil.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 56.998%; Sn 4.059%; As 0.066%; Fe 0.292%
Total 61.416%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Very corroded.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C7

LAB NO: 15033 A and B

Layer: (9)

Depth:

EXCAVATION NO: /402D, NP7, 3-3-66
see NB VII

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU /USA

EXCAVATION REF:

DESCRIPTION: Two fragments of square section bracelet, solid cast. The sample was taken from B.

DIMENSIONS AND WEIGHT:
section: 3 x 3 mm □

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 48.145%; Sn 6.339%; As 0.008%; Fe 0.495%;
Total 54.987%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA AREA: Pit: (5)/(6) int.

LAB NO: 15036 Layer: 1F

Depth:

EXCAVATION NO: NP7, /330A
NNT 251, BN 1, pp.102, 106 (Bronze in stove E*)

MUSEUM NO: Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two droplets of bronze, very corroded.
The sample was taken from A.

DIMENSIONS AND WEIGHT:
weight: A: 0.99 gm
B: 0.15 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.178%; Sn 8.300%; Pb 2.589%; As 0.047%;
Sb 0.049%; Fe 0.041%; Ag 0.129%;
Total 92.334%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

Layer: (6) bottom of (6)

Depth:

LAB NO: 15037

EXCAVATION NO: NP7, /428A
23-3-68

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: Two droplets of bronze, very corroded.

DIMENSIONS AND WEIGHT:

weight: A: 0.88 gm
B; 1.09 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 36.090%; Sn 8.849%; Fe 0.771%
Total 45.711%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4G

Layer: (5)/(6)

Depth:

LAB NO: 15038

EXCAVATION NO: NNT 142

MUSEUM NO:

Plate Nos: 538

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A piece of rather corroded bronze.

DIMENSIONS AND WEIGHT:

weight: 10.36 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.858%; Sn 6.02%; Pb 0.246%; As 1.743%; Sb 0.168%; Fe 0.060%; Ag 0.143%; Ni 0.040%; Co 0.004%; Bi 0.140%; Total 92.422%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Possibly technological waste.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

Layer: (6A)

Depth:

LAB NO: 15039

EXCAVATION NO: NNT 543 /737A

MUSEUM NO:

Plate Nos: 539-548

PERIOD: approx. 500 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a bracelet, very corroded.

DIMENSIONS AND WEIGHT:

section: thickness approx. 3.75 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 68.620%; Sn 7.244%; As 0.014%; Sb 0.005%; Fe 0.146%
Total 76.029%

EPMA: Cu 89.113-91.579%; Sn 9.654-12.888%; Pb 0.017-0.228%; S 0.061-0.131%; As 0.104-0.118%; Fe 0.098-0.279%; Sb 0.059-0.546%; Ni 0.050%; Ag 0.040-0.058%; Au 0.096-0.392%

METALLOGRAPHIC STRUCTURE:

The overall structure is dendritic, but it was heavily corroded especially on the edge. In the middle part there are some areas having an unusual appearance of a needle-like structure in a polygonal grain.

COMMENTS:

The object may be non-uniform in composition, but the overall picture seems to be that of an as-cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4F

Layer: (6) spit 1

Depth:

LAB NO: 15040 A&B

EXCAVATION NO: NNT 247

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1100 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: Two small fragments of bronze, possibly a bracelet or casting spillage; very corroded.

DIMENSIONS AND WEIGHT:

weight: A: 2.99 gm
B: 0.23 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 48.449%; Sn 4.857%; Pb 0.085%; As 0.002%; Fe 0.034%
Total 53.427%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4E

Layer: (5L)

Depth:

LAB NO: 15042

EXCAVATION NO: NNT 141

MUSEUM NO:

Plate Nos: 549

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A very small fragment of a bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

thickness: approx. 2-2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 42.012%; Sn 5.009%; As 0.037%; Fe 0.514%
Total 47.572%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Very corroded.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 1E

Layer: (6U)

Depth:

LAB NO: 15046

EXCAVATION NO: NNT 236

MUSEUM NO:

Plate Nos: 550-556

PERIOD: approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of bronze tool, rectangular section, corroded.

DIMENSIONS AND WEIGHT:

section: 2 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

EPMA: Cu 91.331-92.456%; Sn 5.598-6.745%; Pb 0.173%; S 0.0.8-0.039%; As 0.124-0.173%; Fe 0.139-0.189%; Sb 0.169%; Ni 0.017-0.068%; Ag 0.051-0.092%; Au 0.094-0.260%

ICP: Cu 86.476%; Sn 8.335%; Pb 0.158%; As 0.080%; Sb 0.161%; Fe 0.062%; Ag 0.073%; Ni 0.034%; Co 0.012%; Bi 0.015%
Total 95.406%

AA: Cu 76.775%

METALLOGRAPHIC STRUCTURE:

Only α-phase appears. There is no clear evidence of dendritic structure. The object was cast and then annealed.

COMMENTS:

The object was cast and annealed. The small grain size and extensive corrosion is evidence of heavy working.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4F

LAB NO: 15047

Layer: (6U)

Depth:

EXCAVATION NO: NNT 241

MUSEUM NO:

Plate Nos: 557

PERIOD: approx. 1100 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A very heavily corroded chisel-ended arrowhead, lacking the tang.

DIMENSIONS AND WEIGHT:

width: 2 cm
length: 2.4 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 43.561%; Sn 4.772%; As 0.023%; Fe 0.143%;
Total 48.499%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2F spit-2

Layer: (6)

Depth:

LAB NO: 15048

EXCAVATION NO: NNT 274, 440A, NP7

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Four lumps of bronze, very corroded.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 2.21 gm
B: 0.36 gm
C: 0.16 gm
D: 0.08 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 90.183%; Sn 0.587%; Pb 2.071%; As 0.253%; Sb 0.468%; Fe 0.187%; Ag 0.319%; Ni 0.056%;
Total 103.125%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 1F B.13

Layer: (6)

Depth:

LAB NO: 15050

EXCAVATION NO: 5441, NP7
(/545D Burial 23)

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A complete circular section bracelet, rather corroded. It was solid cast.

DIMENSIONS AND WEIGHT:
bracelet: diameter (outer): 4.5 cm
(inner): 3.6 cm
section: 4 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 61.258%; Sn 9.403%; Pb 11.971%; As 1.109%; Sb 0.135%; Fe 0.699%; Ag 0.237%; Ni 0.033%; Co 0.023%; Bi 0.152%;
Total 85.02%

AA: 85.02%

METALLOGRAPHIC STRUCTURE:

COMMENTS:
As for 15023 (due to the similarity of lead content).

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E6

Layer: (8)

Depth:

LAB NO: 15051

EXCAVATION NO: NP 264

MUSEUM NO:

Plate Nos: 558-563

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a ring with ribbed relief on the surface. The cross-section is rectangular with a convex surface facing outwards.

DIMENSIONS AND WEIGHT:

section: approx. 1.5 x 6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 87.461%

ICP: Cu 91.636%; Sn 0.582%; Pb 11.455%; As 0.826%; Sb 0.488%; Fe 0.013%; Ag 0.380%; Ni 0.151%; Co 0.008%; Bi 0.018%;
Total 105.557%

METALLOGRAPHIC STRUCTURE:

Cored dendrites on a background of (α+δ) eutectoid with a reasonable amount of lead globules.

COMMENTS:

The object was cast by the lost wax process. The decoration was formed as a part of the casting.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (9a)

Depth:

LAB NO: 15052 (A&B)

EXCAVATION NO: /1038D, NP 277, NP 7
27-2-66

MUSEUM NO:

Plate Nos: 564-569

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: Two small fragments of a rectangular section bracelet with circular relief pattern decoration. The sample was taken from A.

DIMENSIONS AND WEIGHT:

A: length: 0.9 cm
width: 0.5 cm
thickness: approx. 2 mm

B: length: 0.8 cm
width: 0.5 cm
thickness: approx. 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.368%; Sn 2.605%; Pb 16.994%; As 1.060%; Sb 0.920%; Fe 0.140%; Ag 0.418%; Ni 0.133%; Co 0.062%; Bi 0.024%;
Total 71.516%

AA: Cu 71.516%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in $(\alpha+\delta)$ eutectoid. There are large casting cavities and large amounts of small balck lead globules.

COMMENTS:

The object was cast by the lost wax process. The decoration was intrinsic to the casting.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: G4

LAB NO: 15053

Layer: (1)

Depth:

EXCAVATION NO: NP 1092

MUSEUM NO:

Plate Nos: 570-576

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of nearly rectangular shaped section bracelet, solid cast.

DIMENSIONS AND WEIGHT:

section: 5 x 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 85.818%; Sn 10.538%; Pb 0.133%; As 0.134%; Sb 0.175%; Fe 0.038%; Ag 0.257%; Ni 0.099%; Co 0.032%; Bi 0.012%;
Total 97.237%

AA: Cu 82.412%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in a background of eutectoid. The dendrites are of well developed form, and of large size.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C5

Layer: (9A)

Depth:

LAB NO: 15054

EXCAVATION NO: NP 1509

MUSEUM NO:

Plate Nos: 577-583

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a small circular relief decorated bracelet. The section was wave shaped.

DIMENSIONS AND WEIGHT:

section: 7 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 84.013%; Sn 2.560%; Pb 15.266%; As 0.680%; Sb 0.533%; Fe 0.041%; Ag 0.312%; Ni 0.100%; Co 0.008%; Bi 0.019%; Total 103.532%

AA: Cu 75.402%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules.

COMMENTS:

The object was cast by lost wax process. The decoration was cast as part of the object. There was no sign of working.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D7

Layer: (9)

Depth:

LAB NO: 15055

EXCAVATION NO: NP 1094

MUSEUM NO:

Plate Nos: 584 and 585

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A complete ring. The section is rectangular with convex surface facing outwards.

DIMENSIONS AND WEIGHT:

diameter: 1.3 cm
section: 0.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The object was not prepared for metallographic study and chemical analysis due to its being a unique piece. From observation, the ring should be cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C7

Layer: (8)

Depth:

LAB NO: 15057

EXCAVATION NO: NP 275

MUSEUM NO:

Plate Nos: 586-591

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a circular-section bracelet, solid cast.

DIMENSIONS AND WEIGHT:

section: 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 78.042%; Sn 6.416%; Pb 16.687%; As 0.151%; Sb 0.149%; Fe 0.077%; Ni 0.018%; Co 0.006%; Bi 0.018%;
Total 101.594%

AA: Cu 74.621%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in $(\alpha+\delta)$ eutectoid. There are large cavities and large amounts of small black lead globules.

COMMENTS:

The object was cast by the lost wax process.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C6 C7

LAB NO: 15058

Layer: (6)/(7)

Depth:

EXCAVATION NO: NP 907

MUSEUM NO:

Plate Nos: 592-595

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a circular section bracelet, solid cast.

DIMENSIONS AND WEIGHT:

section: 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 76.989%; Sn 3.340%; Pb 22.380%; As 0.240%; Sb 0.143%; Fe 0.026%; Ag 0.064%; Ni 0.024%; Co 0.007%; Bi 0.010%;
Total 103.299%

AA: Cu 72.483%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in $(\alpha+\delta)$ eutectoid. There are large casting cavities and large amounts of small black lead globules.

COMMENTS:
The object was cast by the lost wax method, and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E6

LAB NO: 15059

Layer: (9)

Depth:

EXCAVATION NO: NP 1550

MUSEUM NO:

Plate Nos: 596-598

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, solid casting.

DIMENSIONS AND WEIGHT:

section: 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.064%; Sn 6.262%; Pb 12.724%; As 0.074%;
Sb 0.051%; Fe 0.036%;
Total 101.210%

METALLOGRAPHIC STRUCTURE:
Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules.

COMMENTS:
The object was cast by the lost wax process.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C4

Layer: (13)

Depth:

LAB NO: 15060

EXCAVATION NO: NP 1551

MUSEUM NO:

Plate Nos:

PERIOD: approx. 100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a bracelet of approximately rectangular section with convex surface on perimeter, corroded.

DIMENSIONS AND WEIGHT:

section: 3 x 2 mm

D

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 71.036%

ICP: Cu 74.038%; Sn 3.146%; Pb 20.977%; As 0.199%;
Sb 0.143%; Fe 0.020%; Ag 0.064%; Ni 0.021%;
Co 0.006%; Bi 0.014%
Total 98.628%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 15023.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C6

Layer: (19)

Depth:

LAB NO: 15061

EXCAVATION NO: NP 1552

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of circular section, corroded.

DIMENSIONS AND WEIGHT:

section: 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 73.099%; Sn 15.631%; Fe 0.030%;
Total 88.760%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (9)/(10)

Depth:

LAB NO: 15062A

EXCAVATION NO: NP 1553

MUSEUM NO:

Plate Nos: 599-602

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, corroded.

DIMENSIONS AND WEIGHT:

section: 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 75.965%

ICP: Cu 82.272%; Sn 6.792%; Pb 17.065%; As 0.228%; Sb 0.174%; Fe 0.017%; Ag 0.120%; Ni 0.028%; Co 0.010%; Bi 0.044%;
Total 106.75%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules. There are some blue-gray inclusions in some areas. These may be sulphide inclusions or cuprite (no EPMA result, colour of the inclusion used as a guideline).

COMMENTS:
The object was cast and fairly rapidly cooled (as for 15023).

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (9)/(10)

Depth:

LAB NO: 15062 B

EXCAVATION NO: NP 1533

MUSEUM NO:

Plate Nos: 603-606

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of approximately rectangular section, with convex surface facing outwards, corroded.

DIMENSIONS AND WEIGHT:

section: 3 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 65.451%

ICP: Cu 78.538%; Sn 11.630%; Pb 2.036%; As 0.107% ; Sb 0.177%; Fe 0.024%; Ag 0.020%; Ni 0.022%; Co 0.009%; Bi 0.017%;
Total 92.58%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules. There are some pink globules of metallic copper, and some pink patches of redeposited copper in the interdendritic area.

COMMENTS:

The object was cast and fairly rapidly cooled (as for 15023).

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C7

Layer: (9)

Depth:

LAB NO: 15063

EXCAVATION NO: NP 265

MUSEUM NO:

Plate Nos: 607 and 608

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a corroded bracelet of circular section.

DIMENSIONS AND WEIGHT:

section: 3 mm ○

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 85.347%

ICP: Cu 86.204%; Sn 7.601%; Pb 7.054%; As 0.228%; Sb 0.194%; Fe 0.012%; Ag 0.080%; Ni 0.029%; Co 0.009%; Bi 0.025%; Total 101.436%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules. Cuprite inclusions present.

COMMENTS:

The object was cast and fairly rapidly cooled.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E6

Layer: (9a)

Depth:

LAB NO: 15064

EXCAVATION NO: NP 818, NP7, /265D

MUSEUM NO:

Plate Nos: 609

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Eight corroded lumps of copper alloy. The sample was taken from lump A.

DIMENSIONS AND WEIGHT:

weight: Lump A: 1.28 gm
B: 0.95 gm
C: 0.485 gm
D: 0.25 gm

weight: 4 small droplets: 0.24 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 24.953%; Sn 23.829%; Pb 0.729%; As 1.444%; Fe 0.079%;
Ag 0.467%; Bi 0.253%;
Total 51.753%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Very corroded sample.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15066

EXCAVATION NO: NNT 522, NP7, 1592D

MUSEUM NO:

Plate Nos: 610-615

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a rectangular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: approx. 3 x 3.1 mm ▯

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 80.952%

ICP: Cu 84.393%; Sn 6.145%; Pb 0.456%; As 1.651%; Sb 0.154%; Fe 0.075%; Ag 0.361%; Ni 0.077%; Co 0.010%; Bi 0.127%;
Total 93.449%

METALLOGRAPHIC STRUCTURE:

Small cored α-dendrites in (α+δ) eutectoid. The dendrites, in well developed form, radiate from the central part of the section; there are also distributions of very small dots of gray-blue inclusions. These inclusions are very difficult to identify; they may be either sulphides or cuprite.

COMMENTS:

The object must be cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C7

Layer: (9)

Depth:

LAB NO: 15068

EXCAVATION NO: NP 689, NP7, /1738A, 12-1-66

MUSEUM NO:

Plate Nos: 616 and 617

PERIOD:

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A flat bronze fragment rather heavily corroded.

DIMENSIONS AND WEIGHT:
approx. 17 x 5 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 15.171%; Sn 15.013%; Pb 21.468%; As 0.246%;
Fe 0.237%; Bi 0.002%
Total 52.139%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3E

Layer: (5L)

Depth:

LAB NO: 15069

EXCAVATION NO: NNT 185

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a bracelet of square section with convex surface facing outwards, corroded.

DIMENSIONS AND WEIGHT:

section: 3 x 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu84.367%; Sn 9,914%; As 0.013%; Sb 0.027%; Fe 0.089%; Total 94.410%

METALLOGRAPHIC STRUCTURE:

COMMENTS·

CATALOGUE ENTRY

SITE:	NON NOK THA	AREA:	Pit: 2F
LAB NO:	15070		Layer: (6U)
EXCAVATION NO:	NNT 233		Depth:
MUSEUM NO:		Plate Nos:	618-620
PERIOD:	approx. 1100 BC	Fig Nos:	
PRESENT LOCATION:	HU/USA		
EXCAVATION REF:			

DESCRIPTION: A rectangular section bracelet with convex surface facing outwards.

DIMENSIONS AND WEIGHT:

section: 3.5 x 2 mm

D

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 73.308%

ICP: Cu 81.309%; Sn 7.856%; Pb 17.368%; As 0.167%; Sb 0.165%; Fe 0.035%; Ag 0.208%; Ni 0.020%; Co 0.008%; Bi 0.054%; Total 107.19%

METALLOGRAPHIC STRUCTURE:

Unetched structure revealed a lot of lead globules, casting cavities, and uncorroded eutectoid.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15071

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 621-626

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small rectangular-section ring or wire, rather corroded. The ring was distorted and open at the end.

DIMENSIONS AND WEIGHT:

diameter: 1.2-1.4 cm
section: 0.5-1 mm ▯

COMPOSITION: (XRF; EPMA; AA; ICP)
EPMA: Cu 83.406-85.753%; Sn 1.698-2.060%; Fe 0.317-0.372%; Zn 13.266-13.900%

ICP: Cu 73.647%; Sn 2.218%; Pb 5.935%; Fe 0.303%; Ag 0.384%; Ni 0.021%; Bi 0.105%; Zn 18.374%
Total 82.612%

METALLOGRAPHIC STRUCTURE:

Longitudinal section: The structure revealed twinned α-phases and elongated cuprite inclusion. These inclusions are arranged perpendicular to the direction of working.

COMMENTS:

The object was cast, then worked and annealed. This is the only true brass found, but it comes from a disturbed context and may be as late as 1200 AD.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

Layer: (6)/(7)

Depth:

LAB NO: 15074

EXCAVATION NO: NNT 310

MUSEUM NO:

Plate Nos: 627-630

PERIOD: approx. 1800 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet of square section.

DIMENSIONS AND WEIGHT:

section approx. 2 x 2 mm □

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 86.038%; Sn 9.294%; Pb 0.257%; As 0.013%; Fe 0.146%; Ag 0.277%; Ni 0.088%;
Total 97.113%

METALLOGRAPHIC STRUCTURE:

α-dendrites in corroded (α+δ) eutectoid. Cuprite inclusions present.

COMMENTS:

The object must be cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

LAB NO: 15075 A

Layer: (5L) spit 3

Depth:

EXCAVATION NO: NNT 207, /292A
NB 1, p.97, 9-3-68

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of bracelet.

DIMENSIONS AND WEIGHT:
weight: 1.15 gm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 64.374%; Sn 2.127%; Pb 35.726%; As 0.942%; Sb 0.503%;
Fe 0.033%; Ag 0.596%; Ni 0.068%
Total 104.309%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

LAB NO: 15075B

Layer: (5L) spit

Depth:

EXCAVATION NO: NNT 207, /292A
NB 1, p.97, 9-3-68

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small lump of corroded bronze.

DIMENSIONS AND WEIGHT:

weight: 1.07 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 62.081%; Sn 8.468%; As 0.218%; Fe 0.303%;
Ag 0.125%; Bi 0.085%;
Total 71.280%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E4

Layer: (13)

Depth:

LAB NO: 15076

EXCAVATION NO: NP 1536, /248D
18-1-66

MUSEUM NO:

Plate Nos:

PERIOD: approx. 100 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: 3 small pieces of bronze. The corrosion appears as bright green lamellae, and there are also cracks all over the object. The sample was taken from fragment A.

DIMENSIONS AND WEIGHT:

A: 21 x 7 mm
B: 12 x 7 mm
C: 6 x 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 59.671%

ICP: Cu 58.258%; Sn 1.110%; Pb 0.051%; As 0.082%; Sb 0.121%; Fe 0.067%; Ag 0.049%; Ni 0.005%; Co 0.005%; Bi 0.012%;
Total 59.76%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: Baulk E4 E5

Layer: (17)/(18)

Depth:

LAB NO: 15077

EXCAVATION NO: NP 1542

MUSEUM NO:

Plate Nos: 631-634

PERIOD: approx. 1800 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet with convex surface facing outwards. Very heavily corroded.

DIMENSIONS AND WEIGHT:

ection: approx. 8 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 76.718%; Sn 5.695%; Fe 0.112%
Total 82.524%

METALLOGRAPHIC STRUCTURE:

α-dendrites in (α+δ) eutectoid. There are metallic inclusions (copper) with twinning(Pl. 633).

COMMENTS:

It is certainly cast, with a limited amount of working.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C4/D4

Layer: (9)-(17)

Depth:

LAB NO: 15078

EXCAVATION NO: NP 1547, /517D
19-3-66

MUSEUM NO:

Plate Nos: 635

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A conical bronze fragment.

DIMENSIONS AND WEIGHT:

height: 20 mm
diameter (top): 2 mm
(base): 6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 66.924%

ICP: Cu 94.549%; Sn 7.055%; Pb 1.361%; As 0.446%; Sb 0.176%;
Fe 0.029%; Ag 0.419%; Ni 0.049%; Co 0.010%; Bi 0.134%;
Total 104.228%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

LAB NO: 15079

EXCAVATION NO: NNT 189

MUSEUM NO:

PERIOD: Uncertain

PRESENT LOCATION: HU/USA

EXCAVATION REF:

AREA: Pit: 2F

Layer: (5L)

Depth:

Plate Nos: 636-638

Fig Nos:

DESCRIPTION: A small fragment of a square section ring with convex surface facing outwards.

DIMENSIONS AND WEIGHT:

section: approx. 1.5 x 1.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

AA: Cu 65.913%

ICP: Cu 81.335%; Sn 7.198%; Pb 18.706%; As 0.282%; Sb 0.168%; Fe 0.063%; Ag 0.125%; Ni 0.032%; Co 0.008%; Bi 0.022%;
Total 107.939%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in (α+δ) eutectoid. There are large casting cavities and large amounts of small black lead globules and blue-gray inclusions of cuprite.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2F

Layer: (7)

Depth:

LAB NO: 15080

EXCAVATION NO: NNT 328

MUSEUM NO:

Plate Nos:

PERIOD: approx. 2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A small fragment of a bracelet of rectangular section.

DIMENSIONS AND WEIGHT:

section: 4 x 6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 79.821%; Sn 9.971%; Sb 0.013%; Fe 0.040%; Ag 0.167%; Total 90.012%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 15

Layer: (7U)

Depth:

LAB NO: 15081

EXCAVATION NO: NNT 319

MUSEUM NO:

Plate Nos:

PERIOD: approx. 2300 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A triangular bronze fragment, very heavily corroded.

DIMENSIONS AND WEIGHT:

fragment approx. 20 x 23 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 88.829%; As 0.214%; Sb 0.035%; Fe 0.331%; Ag 0.304%;
Total 89.713%

METALLOGRAPHIC STRUCTURE:

COMMENTS:
One of the few copper artifacts identified.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (19)

Depth:

LAB NO: 15085

EXCAVATION NO: NP 812

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two lumps of bronze. The sample was taken from the larger (A).

DIMENSIONS AND WEIGHT:

weight: A: 7.315 gm
B: 0.81 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 67.587%; Sn 8.807%; Fe 0.086%; Ag 0.390%;
Total 76.871%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D4

Layer: (19)

Depth:

LAB NO: 15086

EXCAVATION NO: NP 816

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two lumps of bronze.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 1.03 gm
B: 0.84 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 49.384%; Sn 3.282%; Fe 0.059%; Ag 0.214%
Total 52.940%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: F4

Layer: (13)

Depth:

LAB NO: 15087

EXCAVATION NO: NP 1448

MUSEUM NO:

Plate Nos:

PERIOD: approx. 100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A large bronze lump.

DIMENSIONS AND WEIGHT:

weight: 15.86 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 84.276%; Sn 9.417%; Sb 0.023%; Fe 0.129%;
Total 93.846%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5/E5

Layer: (19)

Depth:

LAB NO: 15088

EXCAVATION NO: NP 1538

MUSEUM NO:

Plate Nos: 639

PERIOD: approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 7.40 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 87.466%; Sn 5.41%; Pb 0.113%; As 0.050%; Sb 0.118%;
Fe 0.030%; Ag 0.134%; Ni 0.017%; Co 0.004%; Bi 0.023%;
Total 93.365%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E4 F4

Layer: (15)

Depth:

LAB NO: 15089

EXCAVATION NO: NP 284

MUSEUM NO:

Plate Nos:

PERIOD: approx. 200 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two droplets of bronze.
Sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 5.80 gm
B: 0.99 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.755%; Sn 5.352%; As 0.183%; Sb 0.027%;
Fe 0.033%; Ag 0.104%; Ni 0.093%; Zn 0.054%;
Total 98.600%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C3 C4

Layer: (18)

Depth:

LAB NO: 15090

EXCAVATION NO: NP 817

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1800-2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 5.64 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 66.305%; Sn 6.916%; Fe 0.054%;
Total 73.276%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D6

Layer: (19)

Depth:

LAB NO: 15091

EXCAVATION NO: NP 1541

MUSEUM NO:

Plate Nos:

PERIOD: approx. 2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two lumps of bronze.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 2.18 gm
B: 0.44 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.685%; Sn 3.683%; Fe 0.037%; Ag 0.097%;
Total 85.501%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15092

EXCAVATION NO:

MUSEUM NO:

Plate Nos:

PERIOD: approx. 2300 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 2.36 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 93.773%; Sn 5.222%; As 0.066%; Sb 0.002%;
Fe 0.017%; Ag 0.235%;
Total 99.316%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E6

Layer: (20)

Depth:

LAB NO: 15093

EXCAVATION NO: NP 1537

MUSEUM NO:

Plate Nos:

PERIOD: approx. 2300 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 10.245 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 87.881%; Sn 6.13%; Pb 0.942%; As 0.552%;
Sb 0.147%; Fe 0.024%; Ag 0.101%; Ni 0.035%;
Co 0.005%; Bi 0.071%
Total 95.888%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: E4 E5

Layer: (17)

Depth:

LAB NO: 15094

EXCAVATION NO: NP 1543

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 3.73 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.480%; Sn 7.25%; Pb 0.498%; As 0.087%; Sb 0.130%;
Fe 0.074%; Ag 0.053%; Ni 0.037%; Co 0.007%; Bi 0.023%;
Total 91.645%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C4 C5

LAB NO: 15 095

Layer: (17)

Depth:

EXCAVATION NO: NP 294

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze which has been cut.

DIMENSIONS AND WEIGHT:
weight: 10.18 gm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 93.659%; Sn 6.259%; As 0.072%; Sb 0.039%;
Fe 0.036%;
Total 100.065%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 1F

Layer: (6) spit 1

Depth:

LAB NO: 15096

EXCAVATION NO: 337A, NNT 231

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 6 droplets or lumps of bronze.
A sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 0.745 gm
B: 0.73 gm
C: 0.76 gm
D: 0.34 gm
E: 0.17 gm
F: 0.17 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 71.712%; Sn 6.222%; Pb 1.985%; Fe 0.361%
Total 80.279%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2F

Layer: (7)

Depth:

LAB NO: 15097

EXCAVATION NO: NNT 329, NP7, 609A

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 3 lumps of bronze, rather corroded. The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 1.895 gm
B: 1.41 gm
C: 0.63 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 61.080%; Sn 4.045%; As 0.002%; Fe 0.291%;
Total 65.419%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: Provenance unknown.

Layer:

Depth:

LAB NO: 15098

EXCAVATION NO: NNT 551, NP7, 1753D

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Three lumps of bronze, rather corroded.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 2.13 gm
B: 2.06 gm
C: 0.84 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 44.219%; Sn 7.913%; Fe 0.314%;
Total 52.446%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

Layer: (5)/(6)

Depth:

LAB NO: 15099

EXCAVATION NO: /248A, NP7
7-3-62

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 7 lumps of bronze.

DIMENSIONS AND WEIGHT:

weight: A: 1.83 gm D: 0.065 gm F: 0.09 gm
B: 0.22 gm E: 0.81 gm G: 0.04 gm
C: 0.32 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 56.619%; Sn 8.700%; Fe 0.122%; Bi 0.0006%
Total 65.442%
(from A)

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2E

Layer: (5)/(6) interface

Depth:

LAB NO: 15100

EXCAVATION NO: NNT 220, NP7, 668A

MUSEUM NO:

Plate Nos: 640-645

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A droplet of bronze.

DIMENSIONS AND WEIGHT:

weight: 2.92 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in corroded (α+δ) eutectoid. There are quite a number of large cavities in the specimen. Gray-blue inclusions present.

COMMENTS:

It was a casting spillage.

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 2E

Layer: (5) (B. II.15,4(6))

Depth:

LAB NO: 15101

EXCAVATION NO: NNT 223, NP7, 524A

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A droplet of bronze.

DIMENSIONS AND WEIGHT:
weight: 9.64 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 87.448%; Sn 6.439%; Pb 0.689%; As 0.036%; Sb 0.019%;
Fe 0.016%;
Total 94.648%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15102

EXCAVATION NO: NNT 202, OF, (5) spit 3
or NP7 /295A, 4F, (5)/(6) interface, 9-3-68.

MUSEUM NO:

Plate Nos: 646-651

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A droplet of bronze.

DIMENSIONS AND WEIGHT:

weight: 2.70 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites in eutectoid. There are a lot of blue-gray inclusions in the eutectoid area. There are some cavities and corroded areas of eutectoid also.

COMMENTS:

Casting spillage.

CATALOGUE ENTRY

SITE: NON NOK THA

LAB NO: 15103

EXCAVATION NO: /1205D, NP7
(S(4) <W. Baulk 110 <N.B.)

MUSEUM NO:

PERIOD: approx. 200BC

PRESENT LOCATION: HU/USA

EXCAVATION REF:

AREA: Pit: E4

Layer: (15)

Depth:

Plate Nos:

Fig Nos:

DESCRIPTION: A droplet of bronze.

DIMENSIONS AND WEIGHT:
weight: 2.65 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 81.378%; Sn 6.405%; Pb 4.03%; As 1.580%; Sb 0.743%;
Fe 0.015%; Ag 0.135%; Ni 0.059%; Co 0.010%; Bi 0.023%;
Total 94.378%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 1E

Layer: (6) top 15 cm.

Depth:

LAB NO: 15104

EXCAVATION NO: NNT 236, NP7, 761A

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1800 AD

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 5 lumps of corroded bronze.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

Weight: A: 5.09 gm
B: 1.08 gm
C: 0.46 gm
D: 0.335 gm
E: 0.07 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 72.995%; Sn 4.871%; As 0.029%; Sb 0.013%;
Fe 0.029%; Ni 0.027%
Total 77.964%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15105A

EXCAVATION NO: NP7, 385A

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A fragment of bronze.

DIMENSIONS AND WEIGHT:

weight: 2.98 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 73.653%; Sn 8.433%; Pb 0.008%; As 0.466%;
Sb 0.035%; Fe 0.189%; Bi 0.019%;
Total 82.805%

METALLOGRAPHIC STRUCTURE:

COMMENTS·

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15105B

EXCAVATION NO: NP7, 385A

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A droplet of bronze.

DIMENSIONS AND WEIGHT:

weight: 3.24 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 88.049%; As 0.057%; Sb 0.049%; Fe 0.014%; Zn 0.056%
Total 89.226%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer:

Depth:

LAB NO: 15107

EXCAVATION NO: NNT 550, NP7, 875D

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze, corroded.

DIMENSIONS AND WEIGHT:

weight: 6.07 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.687%; Sn 8.388%; Sb 0.028%; Fe 0.065%
Total 91.167%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 1E

Layer: (5) spit 3+(6) top

Depth:

LAB NO: 15108

EXCAVATION NO: NNT 221, NP7

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 2 lumps of bronzes (A and B).
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 3.56 gm
B: 3.95 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 85.212%; Sn 7.44%; Pb 0.334%; As 0.949%;
Sb 0.169%; Fe 0.052%; Ag 0.232%; Ni 0.058%;
Co 0.013%; Bi 0.073%
Total 94.506%

AA: Cu 84.885%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 4F

Layer: (5)/(6)

Depth:

LAB NO: 15109

EXCAVATION NO: /162A, NP7 (NNT-225)
29-2-68, NB1 p.68

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: Two lumps of bronze.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 8.10 gm
B: 3.02 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 79.651%; Sn 11.114%; As 0.093%; Sb 0.029%;
Fe 0.007%; Ag 0.027%;
Total 90.921%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer: (6)

Depth:

LAB NO: 15110

EXCAVATION NO: NNT 541, NP7, 1682D

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

weight: 2.44 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 57.355%; Sn 7.381%; Pb 0.104%; As 0.079%; Sb 0.130%; Fe 0.413%; Ag 0.176%; Ni 0.021%; Co 0.007%; Bi 0.003%;
Total 65.669%

AA: Cu 63.191%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer: (6)

Depth:

LAB NO: 15111

EXCAVATION NO: NNT 246 OF (6) sp.1
or NP7 /338A OF (6) sp. 1, 12-3-68

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 3 lumps of bronze, very corroded.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 1.255 gm
B: 0.82 gm
C: 0.98 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 38.635%; Sn 7.699%; Fe 0.961%
Total 47.295%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE:	NON NOK THA	AREA:	Pit:	2E
LAB NO:	15112		Layer:	(5) Bot. 15 cm.
			Depth:	
EXCAVATION NO:	NNT 185			
MUSEUM NO:		Plate Nos:		652
PERIOD:	Uncertain	Fig Nos:		
PRESENT LOCATION:	HU/USA			

EXCAVATION REF:

DESCRIPTION: A lump of bronze, very corroded with lamellar corrosion layers.

DIMENSIONS AND WEIGHT:

weight: 5.69 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 86.014%; Sn 9.899%; Fe 0.128%
Total 96.041%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: D5

Layer: (13)

Depth:

LAB NO: 15113

EXCAVATION NO: NP 1019, /698D
N.B.7, 2, 3.3.66

MUSEUM NO:

Plate Nos:

PERIOD: approx. 100 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A bronze lump with lamellar corrosion products and three very small droplets of bronze. The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 4.75 gm C: 0.15 gm
B: 0.42 gm D: 0.28 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 70.626%; Sn 2.504%; Fe 0.081%;
Total 73.211%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C3

Layer: Fill (15)
Pit in NE corner

Depth:

LAB NO: 15114

EXCAVATION NO: /1197D, 276, NP7,
N.B.7, 4, 26-2-66

MUSEUM NO:

Plate Nos:

PERIOD: approx. 200 BC

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A lump of bronze with corrosion in layers,
and a droplet of bronze.
The sample was taken from the larger lump.

DIMENSIONS AND WEIGHT:

weight: 9.17 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 65.030%; Sn 5.055%; Pb 0.091%; As 0.077%; Sb 0.116%;
Fe 0.023%; Ag 0.123%; Ni 0.009%; Co 0.006%; Zn 0.011%
Total 70.541%

AA: Cu 62.50%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: 3F

LAB NO: 15118

Layer: (6) spit 1

Depth:

EXCAVATION NO: NP7, 367A, NNT 253

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: 3 lumps of bronze, corroded.
The sample was taken from A.

DIMENSIONS AND WEIGHT:

weight: A: 0.53 gm
B: 0.19 gm
C: 0.21 gm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 83.759%; Sn 11.376%; As 0.037%; Sb 0.017%
Fe 0.006%; Ag 0.346%
Total 95.543%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit: C7

Layer: (15)

Depth:

LAB NO: 15136

EXCAVATION NO: NP 808 /600D
NP 7, 15-3-66, see N.B.8, 15/3/66, 13

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION: HU/USA

EXCAVATION REF:

DESCRIPTION: A crescent-shaped piece of bronze.

DIMENSIONS AND WEIGHT:

21 x 9 x 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 30.365%; Sn 13.433%; Fe 0.476%
Total 44.273%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: NON NOK THA

AREA: Pit:

Layer: (5)/(6)

Depth:

LAB NO: 15215

EXCAVATION NO: NNT 217

MUSEUM NO:

Plate Nos:

PERIOD: Uncertain

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A lump of bronze.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 76.379%; Sn 9.281%; Pb 0.206%; Sb 0.039%
Fe 0.114%; Ag 0.353%; Bi 0.101%
Total 87.414%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

SITE 5. BAN NA DI

AMPHOE KUMPHAWAPI, UDORN THANI PROVINCE

Lat.17°15'12"E. and Long.103°06'43"N.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ,

Layer: (43) Removal 1 VII A

LAB NO: 16001

Depth:

EXCAVATION NO: BND' 80, No.1991, No.818 23.1.81

MUSEUM NO:

Plate Nos: 653-655

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A projectile point, heavily corroded. The sample was taken from between the blade and the shaft.

DIMENSIONS AND WEIGHT:

Object: length: 58.44 mm
width (blade): 10.80 mm
width (shaft): 5.44 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 26.631%; Sn 2.372%; Fe 0.202%; Ag 0.627%
Total 29.832%

METALLOGRAPHIC STRUCTURE:

Although the object was very heavily corroded, traces of equi-axial α-grains on a corroded background could be seen.

COMMENTS:

The object was cast, then annealed. The edge may have been worked, but corrosion prevented this being confirmed, although there is some degree of layering in the structure.

CATALOGUE ENTRY

SITE: BAN NA DI

LAB NO: 16002

EXCAVATION NO: BND' 80, No.2281
4.2.81

MUSEUM NO:

PERIOD: Uncertain

PRESENT LOCATION: AD/B

EXCAVATION REF:

AREA: Pit: F6'-SWQ,

Layer: (4)-△1 removal

Depth:

Plate Nos: 656-666

Fig Nos:

DESCRIPTION: A comma-shaped pendant or ornament with a hole. The sample was taken from the thickest part near the top.

DIMENSIONS AND WEIGHT:

overall: 26.16 x 16.12 mm
thickness: 5.86 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 96.464%; Sn 0.157%; Pb 9.129%; As 0.065%; Sb 0.118%; Fe 0.051%: Ag 0.340%; Ni 0.012%; Co 0.002%; Bi 0.021%;
Total 106.359%

METALLOGRAPHIC STRUCTURE:

Cored dendrites in ($\alpha+\delta$) eutectoid. The eutectoid was present in a very small amount due to the low content of tin in the alloy. There are also small black lead globules.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-SWQ

LAB NO: 16003

Layer: (5)-L.VII 10 cm.sp.

Depth:

EXCAVATION NO: BND' 80, No.2286, No.953
5.2.81

MUSEUM NO:

Plate Nos: 667 and 668

PERIOD: Uncertain (approx. 200 BC)

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A chisel ended arrowhead, completely mineralised. The sample was taken from the thickest part of the object.

DIMENSIONS AND WEIGHT:

height: 46.94 mm
width (lower part): 27.50 mm
width (middle part): 14.60 mm
width (top part): 7.86 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 40.799%; Sn 0.754%; Fe 0.358%
Total 41.912%

METALLOGRAPHIC STRUCTURE:

COMMENTS·

The object was not sectioned for metallographic structure due to its condition. It was probably cast, annealed, and probably worked on the cutting edge.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-NE/NW, (5)-15 Removal

LAB NO: 16004

Layer: III

Depth:

EXCAVATION NO: BND'80, No.288, No.54
1.12.80

MUSEUM NO:

Plate Nos: 669-679

PERIOD: approx. 750-1500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: An object of cylindrical shape with a hole along its axis. The hole was still filled with core material. The section was taken from the end of the object.

DIMENSIONS AND WEIGHT:

height: 19.64 mm
diameter: 11.04 mm
diameter (hole): 5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 89.907%; Sn 14.099%; Pb 0.197%; As 0.078%;
Sb 0.036%; Fe 0.209%; Ag 0.281%; Ni 0.048%; Bi 0.025%
Total 104.881%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with a small amount of (α+δ) eutectoid in the interdendritic space.

COMMENTS:

The object was cast; its purpose is uncertain.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-SWQ, (11) - 25

Layer:

Depth:

LAB NO: 16005

EXCAVATION NO: BND'80, No.3258, No.1261
8.3.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 100-200 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A comma-shaped pendant or ornament with a hole for suspension. The sample was taken from the thickest part near the top of the object.

DIMENSIONS AND WEIGHT:

overall: 24.38 x 15.70 mm
thickness: 5.1-7.4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 74.359%; Sn 7.051%; Pb 0.158%; As 0.035%;
Sb 0.041%; Fe 0.237%; Ag 0.278%; Ni 0.030%;
Total 82.189%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 16002.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-NWQ, (1)

Layer: VII - 10 cm sp.

Depth:

LAB NO: 16006

EXCAVATION NO: BND'80, No.1956, No.799
22.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-100 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of a rectangular section bracelet, very corroded.

DIMENSIONS AND WEIGHT:

section: 13.1 x 3.6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 8.845%; Sn 0.797%; Fe 0.456%
Total 10.094%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-SWQ, (7)

LAB NO: 16007

Layer: VII 10 cm sp.

Depth:

EXCAVATION NO: BND'80, No.2404, No.1012
12.2.81

MUSEUM NO:

Plate Nos: 680

PERIOD: approx. 200 BC

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A chisel-ended arrowhead. It was heavily corroded and broken into 3 pieces.

DIMENSIONS AND WEIGHT:

length: 58.88 mm
thickness: 3.4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 57.914%; Sn 0.981%; Fe 0.093%;
Total 58.988%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 16003.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3 NEQ, (35)

Layer: VIIA - 10 cm sp.

Depth:

LAB NO: 16008

EXCAVATION NO: BND'80, No.2151, No.903
29.1.81

MUSEUM NO:

Plate Nos: 681-682

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A chisel-ended arrowhead. The sample was taken from the shaft.

DIMENSIONS AND WEIGHT:

height (overall): 42.46 mm
blade: width: 28.86 mm
thickness: 5.74 mm
shaft: width: 6.1 mm
thickness: 4.14 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 61.084%; Sn 7.646%; Fe 0.131%; Ag 0.036%;
Ni 0.001%; Bi 0.016%
Total 68.974%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

The object was not sectioned for metallographic structure. It was probably cast, annealed, and worked on the cutting edge.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1 SWQ, (1)

Layer: VII - 10 cm sp.

Depth:

LAB NO: 16009

EXCAVATION NO: BND'80, No.1857, No.752
15.1.81

MUSEUM NO:

Plate Nos: 683

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: An arrowhead, very heavily corroded, broken into 3 pieces.

DIMENSIONS AND WEIGHT:
width: 37.12 mm
length: 52.4 mm
thickness: approx. 5.1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 53.826%; Sn 1.436%; Fe 0.083%; Bi 0.017%
Total 55.363%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-NEQ, (11) - 11 Removal

LAB NO: 16010

Layer: VII

Depth:

EXCAVATION NO: BND'80, No.2631, No.1090
20.2.81

MUSEUM NO:

Plate Nos: 684

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Bronze hook with eye. The object is complete, but mineralized. Corrosion product was taken for chemical analysis.

DIMENSIONS AND WEIGHT:

length: 36.6 mm
width: 11.18 mm
thickness: 3.14 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 1.878%; Fe 0.329%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Copper or low tin bronze.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A3/A4, (12)

LAB NO: 16011

Layer: IV . 4/6

Depth:

EXCAVATION NO: BND'80, No.3130, con.No. 2981, No.1206, 5.3.81

MUSEUM NO:

Plate Nos: 685-691

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Casting funnel. The sample was taken from the area near the join between the cone and the shaft.

DIMENSIONS AND WEIGHT:

height: 15.36 mm
width: 10.68 mm
shaft (diameter): 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Sn 23.357%; Pb 94.904%; As 0.073%; Sb 0.434%;
Fe 0.065%; Ag 0.247%; Bi 0.052%
Total 120.133%

METALLOGRAPHIC STRUCTURE:

The structure of the lead rich phase appears as white globules with an interdendritic lamellar eutectoid consisting of lead (white) and tin (dark). There are some casting cavities.

COMMENTS:

This is a discarded casting funnel, but whether from the manufacture of a lead alloy artifact, or an intermediate "lost lead" casting, is uncertain.

CATALOGUE ENTRY

SITE:	BAN NA DI	AREA:	Pit:	A3 - SWQ
LAB NO:	16012		Layer:	(11) - POT.A
			Depth:	
EXCAVATION NO:	No.764, No.139 9.12.80			
MUSEUM NO:		Plate Nos:		
PERIOD:	approx. 300-750 AD	Fig Nos:		
PRESENT LOCATION:	AD/B			

EXCAVATION REF:

DESCRIPTION: Two small fragments of bracelet. The section was rectangular with convex surface on opposite sides. Very badly corroded.

DIMENSIONS AND WEIGHT:

section: 4.16 x 3 mm □

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 21.285%; Pb 8.494%; Fe 0.230%; Ag 0.043%
Total 30.052%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SEQ, (8)

Layer: IV 10 cm sp.

Depth:

LAB NO: 16013

EXCAVATION NO: BND'80, No.482, No.84
3.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 6 fragments of rectangular section bracelets. The sample was taken from the longest fragment which was very badly corroded.

DIMENSIONS AND WEIGHT:
section: 8.34 x 5.12 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 9.543%; Sn 7.928%; Fe 0.443%
Total 17.914%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4 - SEQ, (8)

Layer: IV 10 cm sp.

Depth:

LAB NO: 16014

EXCAVATION NO: BND'80, No.549, No.90
4.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet with a catch at the end.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 68.778%; Sn 16.019%; Pb 26.117%; As 0.073%; Sb 0.021%;
Fe 0.058%; Ag 0.234%; Ni 0.012%; Bi 0.024%
Total 111.336%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-SWQ, (15) 10 cm sp.

LAB NO: 16015

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.853, No.168
11.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet with a catch at one end.

DIMENSIONS AND WEIGHT:

section: diameter: 31.90 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.085%; Sn 3.395%; Pb 11.439%; As 0.470%;
Sb 0.029%; Fe 0.111%; Ag 0.348%; Ni 0.027%;
Bi 0.065%
Total 97.974%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-NEQ, (9) - 2 Removal

LAB NO: 16016

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.610, No.99
4.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, very corroded.

DIMENSIONS AND WEIGHT:

section: diameter: 3.30 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 69.824%; Sn 5.460%; Pb 4.012%; As 0.806%;
Sb 0.068%; Fe 0.186%; Ag 0.148%; Ni 0.034%; Bi 0.136%
Total 80.675%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ, (43)-REM 1

LAB NO: 16017

Layer: VIIA

Depth:

EXCAVATION NO: BND'80, No.1991, No.830
24.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: diameter: 2.92 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 12.619%; Sn 5.438%; Fe 0.176%; Bi 0.033%
Total 18.267%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-NEQ, (12) - 10 cm sp.

LAB NO: 16018

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.773, No.141
9.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 3 fragments of rectangular section bracelet.

DIMENSIONS AND WEIGHT:
section: 3.02 x 1.94 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 62.691%; Sn 10.627%; Pb 13.609%; As 0.449%
Sb 0.115%; Fe 0.091%; Ag 0.338%; Ni 0.021%; Bi 0.089%
Total 88.029%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (14) - 10 cm sp.

LAB NO: 16019

Layer: V

Depth:

EXCAVATION NO: BND'80, No.887, No.192

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:
section: 3.76 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 89.897%; Sn 3.129%; Pb 1.164%; As 0.030%; Sb 0.027%;
Fe 0.069%; Ag 0.153%; Ni 0.017%; Bi 0.012%
Total 94.498%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-ALLQ, (16) - scrap-ing

LAB NO: 16020

Layer: V

Depth:

EXCAVATION NO: BND'80, No.950, No.229
15.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section; 6.08 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 75.905%; Sn 5.919%; Pb 9.009%; As 0.105%;
Sb 0.037%; Fe 0.069%; Ag 0.069%; Ni 0.009%;
Bi 0.009%
Total 91.134%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK (A/3/A4)

Layer: (30) - Layer VII 1 remove

Depth: (A4 Feature A/(30) Ass. B No.18)

LAB NO: 16021

EXCAVATION NO: BND'80, No.3559, No.1370 27.3.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, fairly corroded but some metal still remaining in the central part of the section.

DIMENSIONS AND WEIGHT:

section: 3.84 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 71.896%; Sn 7.808%; Pb 1.1663%; As 0.772%; Sb 0.006%; Fe 0.064%; Ag 0.341%; Ni 0.019%; Bi 0.064%
Total 82.137%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SWQ, (8)-B No.1 Removal

LAB NO: 16022

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.488, No.79
3.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section ring.

DIMENSIONS AND WEIGHT:

section: 2.58 x 2.1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 70.065%; Sn 11.898%; Pb 8.119%; As 0.221%;
Sb 0.077%; Fe 0.109%; Ag 0.406%; Ni 0.023%;
Bi 0.1001%
Total 91.019%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ, (15) 10 cm sp.

LAB NO: 16023

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.852, No.170
11.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of a circular section ring.

DIMENSIONS AND WEIGHT:

section: 5.3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NEQ, (18) 10 cm sp.

LAB NO: 16024

Layer: VI

Depth:

EXCAVATION NO: BND'80, No.1099, No.349
19.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 500 BC-0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of a circular section bracelet.

DIMENSIONS AND WEIGHT:

section: 3.94 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 93.867%; Sn 3.958%; Pb 0.746%; As 0.058%; Sb 0.041%;
Fe 0.048%; Ag 0.538%; Ni 0.013%; Bi 0.051%; Zn 0.015%
Total 99.336%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ, (19) 10 cm sp.

Layer:

Depth:

LAB NO: 16025

EXCAVATION NO: BND'80, No.1020, No.275
17.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:
section: 3.54 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 91.501%; Sn 8.511%; Pb 2.387%; As 0.219%; Sb 0.080%;
Fe 0.046%; Ag 0.102%; Ni 0.026%; Bi 0.008%; Zn 0.025%;
Total 102.906

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SWQ, (11) 10 cm sp.

Layer: IV

Depth:

LAB NO: 16026

EXCAVATION NO: BND'80, No.779, No.145
9.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 3.54 x 2.76 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 77.197%; Sn 10.179%; Pb 4.069%; As 0.526%; Sb 0.109%
Fe 0.077%; Ag 0.344%; Ni 0.034%; Bi 0.111%
Total 92.648%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-SEQ, (20) 10 cm sp.

LAB NO: 16027

Layer: VI

Depth:

EXCAVATION NO: BND'80, No.1052, No.305

MUSEUM NO:

Plate Nos:

PERIOD: 500 - 0 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet with a catch at one end.

DIMENSIONS AND WEIGHT:

section: 3.72 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 74.274%; Sn 8.427%; Pb 8.858%; As 0.129%; Sb 0.062%
Fe 0.109%; Ag 0.201%; Ni 0.014%; Bi 0.011%
Total 92.087%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SEQ, (10) 10 cm spit

LAB NO: 16028

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.688, No.143
9.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet.

DIMENSIONS AND WEIGHT:

section: 3 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 64.681%; Sn 9.936%; Pb 15.353%; As 0.803%; Sb 0.116%;
Fe 0.070%; Ag 0.104%; Ni 0.037%; Bi 0.183%
Total 91.285%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NWQ, (6) 10 cm sp.

LAB NO: 16029

Layer: III

Depth:

EXCAVATION NO: BND'80, No.319, No.56
29.11.80

MUSEUM NO:

Plate Nos: 692-697

PERIOD: approx. 750-1500 AD

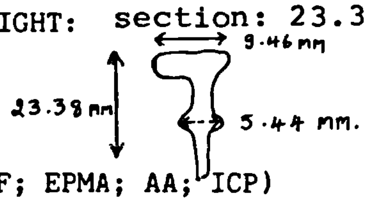
Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of rim of a container or bracelet, completely mineralized.

DIMENSIONS AND WEIGHT: section: 23.38 x (9.46; 5.44) mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 55.078%; Sn 6.703%; Pb 0.007%; Sb 0.034%; Fe 0.134%
Ag 0.198%
Total 62.155%

METALLOGRAPHIC STRUCTURE:

α-phase in the corroded unidentified background. In some areas the corroded background showed features of β-martensite.

COMMENTS:

The object might be cast and quenched from the (α+β) region (586^{o}-798^{o}C) into water.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NWQ, (32) 10 cm sp.

Layer: VII A

Depth:

LAB NO: 16030

EXCAVATION NO: BND'80, No.2000, No.826
24.1.81

MUSEUM NO:

Plate Nos:

PERIOD: 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 4.22 x 5.20 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 43.502%; Sn 2.952%; Fe 0.199%; Ag 0.023%
Total 46.676%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-NWQ, (17)-POT.B

LAB NO: 16031

Layer: V

Depth:

EXCAVATION NO: BND'80, No.1138, No.427
19.12.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A group of fragments of circular section bracelets (4 pieces) and a nearly complete circular section bracelet. The sample was taken from the nearly complete bracelet.

DIMENSIONS AND WEIGHT:

section: 4.14 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 52.219%; Sn 11.456%; Sb 0.021%; Fe 0.093%
Total 63.789%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-NWQ, (9) - 18 removal

LAB NO: 16032 BND'80, No.2480, No.1048 16.2.81

Layer: VII

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 698

PERIOD: approx. 800-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two spheres of bronze fused together.

DIMENSIONS AND WEIGHT:
height: 19.06 mm
width: 9.62 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 59.394%; Sn 7.002%; As 0.005%; Sb 0.016%;
Fe 0.277%; Ag 0.222%; Ni 0.004%; Bi 0.009%
Total 66.929%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NWQ, (9) 10 cm sp. 4.12.80
Layer: IV
Depth:

LAB NO: 16033

EXCAVATION NO: BND'80, No.592, No.98

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rim of a container or bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 32.4 x (10.2; 7.4; 4.8) mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 28.257%; Sn 0.982%; Fe 0.248%
Total 29.609%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NWQ, (8) 10 cm sp.

Layer: IV

Depth:

LAB NO: 16034

EXCAVATION NO: BND'80, No.506, No.83
3.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a container or bracelet, completely mineralized. (See photograph of obj. no. 16029.)

DIMENSIONS AND WEIGHT:

section: 11.14 x (33.16; 7.66; 3.64; 6.42) mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 57.372%; Sn 12.106%; Pb 0.091%; As 0.045%; Sb 0.062%
Fe 0.101%; Ag 0.077%
Total 69.855%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 16029.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NEQ (18) 10 cm sp.

Layer: VI

Depth:

LAB NO: 16036

EXCAVATION NO: BND'80, No.1099, No.348
19.12.80

MUSEUM NO:

Plate Nos: 699-701

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of a lunate section bracelet.

DIMENSIONS AND WEIGHT:

section: 6 x 8.06 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 55.285%; Sn 9.578%; Pb 0.193%; Sb 0.002%; Fe 0.061%;
Ni 0.008%; Bi 0.008%
Total 65.135%

METALLOGRAPHIC STRUCTURE:

The specimen was heavily corroded, but some traces of α-phase still remained.

COMMENTS:

Cast and annealed.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NWQ, (8) 10 cm sp.

Layer: III

Depth:

LAB NO: 16037

EXCAVATION NO: BND'80, No.472, No.75
3.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 750-1500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two small fragments of a circular section ring, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 3.6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 55.333%; Sn 14.024%; Sb 0.051%; Fe 0.058%
Total 69.467%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SEQ, (13) 10 cm s]

LAB NO: 16038

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.893, No.193
12.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section ring, with metal remaining in the centre.

DIMENSIONS AND WEIGHT:

section: 3.68 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 96.678%; Sn 1.148%; Pb 0.720%; As 0.049%; Sb 0.037%;
Fe 0.058%; Ag 0.157%; Ni 0.013%; Bi 0.015%; Zn 0.005%
Total 98.881%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A3/A4

Layer: (7)-L.III B. No.2

Depth:

LAB NO: 16039

EXCAVATION NO: BND'80, No.2925, No.1160
27.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 750-1500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A complete rectangular section ring.

DIMENSIONS AND WEIGHT:

section: 3 x 4 mm
diameter (outer): 22.7 mm
(inner): 17.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 56.053%; Sn 15.776%; Pb 3.240%; As 0.271%; Sb 0.066%;
Fe 0.163%; Ag 0.021%; Ni 0.039%; Bi 0.063%
Total 75.693%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-SEQ, 6 - (40)

LAB NO: 16040

Layer: VII A

Depth:

EXCAVATION NO: BND'80
21.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A group of circular section bracelets, completely mineralized. The sample was taken from the largest piece.

DIMENSIONS AND WEIGHT:

section: 3.68 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 56.668%; Sn 4.677%; Fe 0.207%
Total 61.552%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (6) 10 cm sp.

LAB NO: 16041

Layer: III

Depth:

EXCAVATION NO: BND'80, No.407, No.62
2.12.80

MUSEUM NO:

Plate Nos: 702

PERIOD: approx. 750-1500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Four fragments of rectangular section rings. Three pieces are the same size, the fourth is smaller. The sample was taken from one of the larger fragments.

DIMENSIONS AND WEIGHT:

section (large): 3 x 4 mm; section (small): 1.8 x 2.76 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 33.812%; Sn 5.876%; Pb 1.233%; As 0.032%;
Sb 0.003%; Fe 0.207%; Zn 0.057%
Total 41.222%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-SEQ, (40) 10 cm sp.

Layer: VII B

Depth:

LAB NO: 16042

EXCAVATION NO: BND'80, No.2356, No.987
7.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1500-1000 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 3.24 x 6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 24.633%; Sn 12.357%; As 0.013%; Fe 0.291%;
Ag 0.052%; Bi 0.445%
Total 37.391%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SWQ, (3) 10 cm sp.

Layer: II

Depth:

LAB NO: 16043

EXCAVATION NO: BND'80, No.96, No.12
25.11.80

MUSEUM NO:

Plate Nos: 703-708

PERIOD: approx. 1500-1850 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A piece of bronze (possibly part of a container), heavily corroded.

DIMENSIONS AND WEIGHT:

section: 5.8 x 8.38 x 2.06 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 20.237%; Sn 8.983%; Fe 0.765%; Ag 0.002%; Bi 0.008%
Total 29.996%

METALLOGRAPHIC STRUCTURE:

The object was very badly corroded. The structure is α-phase on a corroded, unidentified, background. In some areas the corroded background showed features of β-martensite.

COMMENTS:

The object may have been cast and quenched from the (α+β) region (586^{o}-$798^{o}C$) into water.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-NWQ, (14) - 2

LAB NO: 16044

Layer: V

Depth:

EXCAVATION NO: BND'80, No.876, No.182
11.12.80

MUSEUM NO:

Plate Nos:

PERIOD: 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet.

DIMENSIONS AND WEIGHT:

section: 3.4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 75.342%; Sn 8.137%; Pb 22.107%; As 0.165%; Sb 0.095%;
Fe 0.057%; Ag 0.387%; Ni 0.030%; Bi 0.011%;
Total 106.331%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-ALLQ, (9)-Separating

LAB NO: 16045

Layer: IV

Depth:

EXCAVATION NO: BND'80
4.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 1.76 x 6.08 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 48.366%; Sn 14.265%; Pb 0.042%; As 0.016%; Sb 0.089%
Fe 0.176%; Ni 0.009%
Total 62.962%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (16) - 3

Layer: V

Depth:

LAB NO: 16046

EXCAVATION NO: BND'80, No.970, No.234
15.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet.

DIMENSIONS AND WEIGHT:

section: 3.4 x 3.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 92.619%; Sn 4.248%; Pb 0.255%; As 0.078%; Sb 0.064%;
Fe 0.054%; Ag 0.164%; Ni 0.018%; Bi 0.015%; Zn 0.023%;
Total 97.538%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SWQ, (13) 10 cm spit

LAB NO: 16047

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.874, No.187
12.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet with a convex surface facing outwards. It was completely corroded.

DIMENSIONS AND WEIGHT:

section: 2.28 x 3.30 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 56.642%; Sn 14.928%; Pb 0.022%; Sb 0.051%; Fe 0.061%
Total 71.704%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A3/A4, (6)

Layer: III 10 cm spit

Depth:

LAB NO: 16048 A and B

EXCAVATION NO: BND'80, No. 2887, No.<u>1153</u>
27.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 750-1500 AD

Fig Nos:

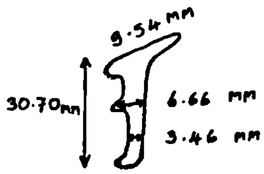
PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of bracelet or container. The fragments completely corroded. The sample was taken from A. (See 16029.)

DIMENSIONS AND WEIGHT:

section: 9.54 x 30.70 x 3.46 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 42.132%; Sn 3.929%; Fe 0.208%; Ag 0.164%;
Ni 0.001%; Bi 0.017%
Total 46.451%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NEQ, (41) 10 cm spit

LAB NO: 16049

Layer: VII B

Depth:

EXCAVATION NO: BND'80, No.2457, No.1036
16.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1500-1000 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of rectangular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

section: 2.28 x 3.46 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 54.934%; Sn 8.556%; Fe 0.265%; Ni 0.034%; Bi 0.012%;
Zn 0.077%
Total 63.877%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (19) 10 cm sp.

Layer: VI

Depth:

LAB NO: 16050

EXCAVATION NO: BND'80, No.1126, No.360
19.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: The fragments of C-section bracelet.

DIMENSIONS AND WEIGHT:

section: 7.8 x 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 39.212%; Sn 0.049%; Pb 2.303%; As 0.082%; Fe 0.138%
Total 41.784%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-SEQ, (12) 10 cm sp.

LAB NO: 16051

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.794, No.154
10.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section ring with a convex surface facing outwards, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 3.18 x 4.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 32.309%; Sn 8.694%; Pb 3.098%; As 0.039%; Fe 0.416%
Total 44.556%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: Al-W.section, (19) - Pot C.B No.8 (lower)

Layer: IV

Depth:

LAB NO: 16052

EXCAVATION NO: BND'80, No.3615, No.1431 1.4.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 4 fragments of a rectangular section bracelet, corroded completely.

DIMENSIONS AND WEIGHT:

section: 1.76 x 2.6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 52.813%; Sn 14.621%; Fe 0.005%
Total 67.439%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ, (16) 10 cm sp.

Layer: IV

Depth:

LAB NO: 16053

EXCAVATION NO: BND'80, No.888, No.195
12.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of rectangular section rings, completely corroded.

DIMENSIONS AND WEIGHT:

section: 2 x 5.28 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 54.681%; Sn 5.040%; Pb 0.215%; As 0.097%; Fe 0.065%
Total 60.099%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A2/A3, (9)

LAB NO: 16054

Layer: IV 10 cm spit

Depth:

EXCAVATION NO: BND', No.2930, No.1162
28.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section ring with a convex surface facing outwards.

DIMENSIONS AND WEIGHT:

section: 3 x 3.06 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 37.202%; Sn 12.248%
Total 49.450%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NWQ, (14) 10 cm sp.

LAB NO: 16055

Layer: v

Depth:

EXCAVATION NO: BND'80, No.922, No.215
13.12.80

MUSEUM NO:

Plate Nos:

PERIOD: 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a circular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

diameter: 4.46 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 68.012%; Sn 0.925%; Pb 4.599%; As 0.036%; Fe 0.059%
Total 73.632%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit:A1-NWQ, (11) 10 cm sp.

LAB NO: 16056

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.743, No.126
9.12.80

MUSEUM NO:

Plate Nos: 709

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two fragments of rectangular rings with the convex surface facing outwards.

DIMENSIONS AND WEIGHT:

section: 2.1 x 3.62 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 49.145%; Sn 18.272%; Pb 0.234%; As 0.017%; Fe 0.815%
Total 68.484%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A2/A3, (11)

Layer: IV 10 cm sp.

Depth:

LAB NO: 16057

EXCAVATION NO: BND', No.2978, No.1175
2.3.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section ring, completely corroded.

DIMENSIONS AND WEIGHT:

section: 1.48 x 2.60 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 52.118%; Sn 3.132%; Pb 6.124%; As 0.018%; Fe 0.326%
Total 61.719%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-SWQ, (13) 10 cm sp.

LAB NO: 16058

Layer: V

Depth:

EXCAVATION NO: BND'80, No.822, No.161
10.12.80

MUSEUM NO:

Plate Nos: 710-714

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 3 fragments of rectangular section ring.

DIMENSIONS AND WEIGHT:

section: 2.86 x 3.80 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 91.564%; Sn 6.404%; Pb 1.099%; As 0.056%; Fe 0.064%
Total 99.188%

METALLOGRAPHIC STRUCTURE:

Cored α-dendrites with very little (α+δ) eutectoid.
There are a few black lead globules.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit:A2-SEQ, (16) 10 cm sp.

Layer: IV

Depth:

LAB NO: 16059

EXCAVATION NO: BND'80, No.905, No.203
12.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet.

DIMENSIONS AND WEIGHT:

section: 4.1 x 5.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 82.189%; Sn 9.145%; Pb 10.977%; As 0.202%;
Fe 0.405%; Ag 0.022%
Total 102.939%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-NEQ, (34) 10cm sp.

LAB NO: 16060

Layer: VII A

Depth:

EXCAVATION NO: BND'80, No.2093, No.869
27.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000 BC-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two very small fragments of bracelets, heavily corroded. The sections are circular and rectangular. The sample was taken from the rectangular section.

DIMENSIONS AND WEIGHT:

section: 4.74 x 5.44 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 50.061%; Sn 5.582%; Fe 0.080%
Total 55.723%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A2/A3, (33) 10cm sp.

LAB NO: 16061

Layer: VII B

Depth:

EXCAVATION NO: BND'80, No.3431, No.1290 14.3.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1500-1000 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 4 fragments of circular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

section: diameter: 4.94 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 66.279%; Sn 4.968%; Fe 0.007%; Ag 0.007%
Total 71.261%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-SEQ, (17) pot B/(16)

LAB NO: 16062

Layer:

Depth:

EXCAVATION NO: BND'80, No.933, No.214
15.12.80

MUSEUM NO:

Plate Nos: 715

PERIOD: 500 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet with convex surface facing outwards, completely corroded.

DIMENSIONS AND WEIGHT:

section: approx. 8.56 x 2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 43.627%; Sn 20.888%
Total 64.516%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-SEQ, (14) 10 cm sp.

Layer: V

Depth:

LAB NO: 16063

EXCAVATION NO: BND'80, No.894, No.200
12.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Eight fragments of circular section bracelets, completely corroded.

DIMENSIONS AND WEIGHT:

diameter: 2.2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 53.629%; Sn 14.318%; Sb 0.124%; Fe 0.023%
Total 68.095%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (12) 10 cm sp.

LAB NO: 16064

Layer: IV

Depth:

EXCAVATION NO: BND'80, No.753, No.133

MUSEUM NO:

Plate Nos: 716-726

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, rather corroded.

DIMENSIONS AND WEIGHT:

section: 1.6 x 5.16 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 62.057%; Sn 29.455%; As 0.109%; Sb 0.012%; Fe 3.598%; Ni 0.009%
Total 95.242%

METALLOGRAPHIC STRUCTURE:

The structure revealed a large grain of partially decomposed β_2 phase with some (α+δ) eutectoid inside the grain. The α-phase formed along the original β-grain boundaries. The leaf-like phase is α-phase. The α and δ phases seem to form a Widmanstätten pattern. The very dark dots are iron inclusions; before etching these appear as silvery metallic inclusions (Pl.717, 718 and 725).

COMMENTS:

The object was cast and quenched from the γ-region (β_1 ordered region) at around 600°C into water.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SEQ, (24) 10 cm sp.

LAB NO: 16065

Layer: VII A

Depth:

EXCAVATION NO: BND'80, No.1451, No.693
2.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of a rectangular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

section: 3 x 13.6 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 38.137%; Sn 7.796%; Fe 0.124%
Total 46.058%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SWQ, (33) 10 cm sp.

LAB NO: 16066

Layer: VII A

Depth:

EXCAVATION NO: BND'80, No.2612, No.1086
19.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Three fragments of circular section bracelets, heavily corroded.

DIMENSIONS AND WEIGHT:

section: 4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 57.724%; Sn 4.824%; Fe 0.008%
Total 62.556%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A1-NWQ, (13) 10 cm sp.

Layer: V

Depth:

LAB NO: 16067

EXCAVATION NO: BND'80, No.855, No.174
11.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of a rectangular section bracelet.

DIMENSIONS AND WEIGHT:
section: 2.52 x 3.28 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 44.71%; Sn 26.999%; Fe 0.088%
Total 71.799%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: BAULK A3/A4, (20) 10 cm spit

LAB NO: 16068

Layer: VI

Depth:

EXCAVATION NO: BND'80, No.3267, No.1258 8.3.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

section: 6.4 x 7.28 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 62.411%, Sn 6.461%; Fe 0.005%
Total 68.878%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NWQ, (15) 10 cm sp.

Layer: IV

Depth:

LAB NO: 16069

EXCAVATION NO: BND'80, No.857, No.176
11.12.80

MUSEUM NO:

Plate Nos: 727-736

PERIOD: approx. 300-750 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet, completely corroded.

DIMENSIONS AND WEIGHT:

section approx. 4.5 x 25.42 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 59.132%; Sn 20.210%; Fe 0.023%
Total 79.366%

METALLOGRAPHIC STRUCTURE:

Twinned α-phase in (α+δ) eutectoid. The α-phase is small. There are cuprite inclusions lying perpendicular to the direction of working.

COMMENTS:

The object was cast then worked and annealed.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-SEQ, (5)

Layer: VII

Depth:

LAB NO: 16070

EXCAVATION NO: BND'80, No.2367, No.989
9.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 200 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A small fragment of distorted shaped bracelet, heavily corroded.

DIMENSIONS AND WEIGHT:

thickness: approx. 2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 57.304%; Sn 0.491%; Fe 1.984%
Total 59.779%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit:

LAB NO: 16071

Layer: (23) - B No.16, Asso. B No.16

Depth:

EXCAVATION NO: BND'80, No.137
25.4.80

MUSEUM NO:

Plate Nos:

PERIOD:

Fig Nos:

PRESENT LOCATION: Otago University, New Zealand.

EXCAVATION REF:

DESCRIPTION: A group of 3 bronze rectangular section bracelets. Two of them are complete, one was broken.

DIMENSIONS AND WEIGHT:
section: 5.1 x 7.24 mm
diameter (outer): 58.34 mm
(inner): 44.86 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 91.558%; Sn 4.85%; As 3.557%; Fe 0.067%
Total 100.037%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SEQ, (19) 10 cm sp.

LAB NO: 16072

Layer: VI

Depth:

EXCAVATION NO: BND'80, No.1126, No.361 19.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Two pieces of bronze, heavily corroded. The sample was taken from the larger piece.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 60.799%; Sn 5.944%; Fe 0.017%
Total 66.760%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-NEQ, (18) 10 cm sp.

Layer: v

Depth:

LAB NO: 16073

EXCAVATION NO: BND'80, No.1049, No.298
17.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Three pieces of bronze, heavily corroded.
The sample was taken from the largest piece.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 42.709%; Sn 11.660%; Pb 0.568%; Sb 0.035%;
Fe 0.008%; Ag 3.761%
Total 58.743%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-NWQ, (14) 10 cm sp.

Layer: V

Depth:

LAB NO: 16074

EXCAVATION NO: BND'80, No.860, No.178
11.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A group of bronze droplets.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 73.003%; Sn 12.028%; Pb 12.831%; As 0.136%
Sb 0.511%; Fe 0.021%
Total 98.530%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Casting spillage.

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A3-SWQ, (17) 10cm sp.

LAB NO: 16075

Layer: VI

Depth:

EXCAVATION NO: BND'80, No.1050, No.294
17.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: 4 small lumps of very corroded bronze.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 55.507%; Sn 0.855%; Pb 0.704%; Fe 0.119%
Total 57.186%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: F6'-NEQ, (10) 10 cm spit

LAB NO: 16076

Layer: VII

Depth:

EXCAVATION NO: BND'80, No.2584, No.1084
19.2.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A very small fragment of bronze, completely corroded.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 48.806%; Sn 10.362%; As 0.166%; Fe 0.221%;
Ag 0.092%; Bi 0.020%
Total 59.667%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A4-SWQ, (15) 10 cm sp.

LAB NO: 16077

Layer: V

Depth:

EXCAVATION NO: BND'80, No.943, No.222
15.12.80

MUSEUM NO:

Plate Nos:

PERIOD: approx. 0-300 AD

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: Bronze droplets, very corroded.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 53.060%; Sn 4.593%; Pb 6.090%; As 0.130%
Fe 0.050%
Total 63.924%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit: A2-NEQ, (38) 10 cm sp.

Layer: VII A

Depth:

LAB NO: 16078

EXCAVATION NO: BND'80, No.1787, No.726
13.1.81

MUSEUM NO:

Plate Nos:

PERIOD: approx. 1000-500 BC

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A group of droplets, very corroded.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 72.684%; Sn 3.559%
Total 76.243%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE: BAN NA DI AREA: Pit: A4-NWQ, (19) 10 cm sp.

LAB NO: 16079 Layer: VI

Depth:

EXCAVATION NO: BND'80, No.111, No.345
19.12.80

MUSEUM NO: Plate Nos:

PERIOD: approx. 500 BC - 0

Fig Nos:

PRESENT LOCATION: AD/B

EXCAVATION REF:

DESCRIPTION: A group of droplets, completely corroded.

DIMENSIONS AND WEIGHT:

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 39.930%; Sn 3.602%; As 0.787%; Sb 0.049%
Fe 0.086%
Total 44.455%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

CATALOGUE ENTRY

SITE:	BAN NA DI	AREA:	Pit: F6'-SEQ, (7)
LAB NO:	16080		Layer: VII 10 cm sp.
			Depth:
EXCAVATION NO:	BND'80, No.2403, No.1014 12.2.81		
MUSEUM NO:		Plate Nos:	737
PERIOD:	approx. 200 BC		
		Fig Nos:	
PRESENT LOCATION:	AD/B		
EXCAVATION REF:			

DESCRIPTION: A completely corroded barbed arrowhead.

DIMENSIONS AND WEIGHT:

length: approx. 26 mm
width: approx. 22 mm
thickness: approx. 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF of corrosion products revealed presence of tin and copper.

METALLOGRAPHIC STRUCTURE:

COMMENTS:

As for 16008.

SITE 6. BAN DON TA PHET

AMPHOE PHANOM THUAN, KANCHANABURI PROVINCE

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

LAB NO: 18001

Depth:

EXCAVATION NO: 2099 or 2097

MUSEUM NO:

Plate Nos: 738-745

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: IOA/L

EXCAVATION REF:

DESCRIPTION: A fragment of a rectangular section bracelet. There is a dark patina on the surface.

DIMENSIONS AND WEIGHT:

section: 12 x 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 84.964%; Sn 26.777%; Sb 0.063%; Fe 0.011%; Ag 0.538%
Total 112.354%

METALLOGRAPHIC STRUCTURE:
The structure revealed much α-phase (yellow leaf-like areas) on a background of fine long thin needles of β'-(banded) martensite. Some β_1'-martensite (coarse acicular) is found in some areas near the edge of the specimen, mixed with the β'-martensite. There is no sign of twinning in the α-phase.

COMMENTS:
The tin content of this object was 26.7 wt.% Sn. The object was very likely cast and heated up to above 560°C (into the $\alpha+\beta_1$ or $\alpha+\gamma$ region) then quenched into water.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18002

EXCAVATION NO: 2097

MUSEUM NO:

Plate Nos: 746-752

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: IOA/L

EXCAVATION REF:

DESCRIPTION: A fragment of bracelet of lunate section with convex surface facing outwards. The patina on the surface is olive coloured.

DIMENSIONS AND WEIGHT:

section: 12 x 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 75.057%; Sn 24.933%; As 0.059%; Fe 0.141%; Ni 0.026%
Total 100.217%

METALLOGRAPHIC STRUCTURE:

The structure is twinned α-phase in a β_1'-martensite (acicular). The α-phase is rounded and twinned, which indicates that this object was cast then hot worked and annealed in the (α+β) range (600-800^{o}C) and quenched in water. The martensite is coarse and compact. The amount of α-phase is less than of β_1'-martensite. The unetched sample showed elongated cuprite inclusions.

COMMENTS:

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18003

EXCAVATION NO: 886

MUSEUM NO:

PERIOD: 1810±210 B.P.

PRESENT LOCATION: IOA/L

Plate Nos: 753-761 and 837

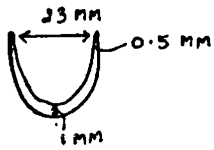
Fig Nos:

EXCAVATION REF:

DESCRIPTION: A nearly complete U-shaped bracelet.

DIMENSIONS AND WEIGHT:

thickness: 0.5-1 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 74.572%; Sn 21.026%; Pb 0.476%; As 0.025%
Fe 0.214%; Ag 1.022%
Total 97.336%

METALLOGRAPHIC STRUCTURE:

α-dendrites of well developed form on a background of β_1'-martensite needles (compact needles). Gray-blue cuprite inclusions are not elongated (Pl.759). Under very high magnification there are some black dots in the martensite area. These may be impurities or small casting cavities. In some areas the original boundaries of the β-grains still remain (Pl.758). Under high magnification, the α-phase revealed a pale blue envelope on its edge (Pl.758 and 759).

COMMENTS:

The object was cast, slow cooled and heated up again to the temperature of the (α+β) range (600°C-800°C), and held at this temperature insufficiently long to completely anneal the dendritic α-phase, then quenched in water. There was no sign of working in the structure. There is no photograph of this object. Pl.837 is representative of this type of bracelet.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

LAB NO: 18004

Layer:

Depth:

EXCAVATION NO: 3490, (79)

MUSEUM NO:

Plate Nos: 762

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: IOA/L

EXCAVATION REF:

DESCRIPTION: A bronze bell with rather smooth surface and dark green patina. There is a lump of metal inside and a loop on the top of the bell. It is heavily corroded.

DIMENSIONS AND WEIGHT:

bell: 20 x 9 mm
thickness: approx. 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 85.693%; Sn 3.473%; Pb 15.506%; As 0.1305%; Fe 1.153%
Ag 0.346%; Ni 0.145%; Co 0.017%
Total 106.464%

METALLOGRAPHIC STRUCTURE:

COMMENTS:

Pl.762 is representative of this type of bell.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18005

EXCAVATION NO: $\triangle$3490, (79)

MUSEUM NO:

Plate Nos: 762-766

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: IOA/L

EXCAVATION REF:

DESCRIPTION: A bronze bell with rough surface and dark green patina. There was a piece of metal inside, and a loop on top of the bell; heavily corroded.

DIMENSIONS AND WEIGHT:

height: 20 mm
width: 9 mm
thickness: 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 67.274%; Sn 7.997%; Pb 25.655%; As 0.169%; Fe 0.118%
Ag 0.321%; Ni 0.116%
Total 101.652%

METALLOGRAPHIC STRUCTURE:

α-dendrites in very small areas of eutectoid. There are a lot of casting cavities and black lead particles.

COMMENTS:

The bell was cast in one piece by the lost wax process with a lump of metal inside the bell. The top part of the loop was completely corroded.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

LAB NO: 18006A (P 31, RIM)

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 767 and 768

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of the rim of a thin bowl. Corroded.

DIMENSIONS AND WEIGHT:

thickness: approx. 2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 73.630%; Sn 23.214%; As 0.011%; Sb 0.037%; Fe 0.049%
Ag 1.527%
Total 98.469%

METALLOGRAPHIC STRUCTURE:

Very small twinned α-phase in background of very fine needles of β_1' martensite.

COMMENTS:
The object was cast, slightly worked in the hot state, annealed to the temperature of the (α+β) range (798°C-586°C) and quenched.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18006 B (P 31, body)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 769 and 770

PERIOD: 1810 $\pm$ 210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a thin container.

DIMENSIONS AND WEIGHT:

thickness: approx. 0.3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:
Very small twinned α-phase in a background of β_1' martensite.

COMMENTS:
The object was cast, slightly worked in the hot state, annealed to the temperature of the $(\alpha+\beta)$ range ($798^{o}C$-$586^{o}C$) and quenched.

Hardness: $H_v = 209.4$ (martensite)

CATALOGUE ENTRY

SITE: BAN DON TA PHET | AREA: Pit:

LAB NO: 18007 (P5 or P6, rim) | Layer:

EXCAVATION NO: | Depth:

MUSEUM NO: 530/2519 | Plate Nos:

PERIOD: 1810±210 B.P. | Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of the rim of a container (thick bowl), metal sound, decorated, sectioned through the "dot and circle" decoration.

DIMENSIONS AND WEIGHT:

thickness: 1.5-2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)
ICP: Cu 71.235%; Sn 21.829%; As 0.269%; Sb 0.055%; Fe 0.399%; Ni 0.163%; Co 0.048%; Total 94.0005%
EPMA: Alpha phase: Cu 84.43-84.48%; Sn 14.64-14.69%; Pb ~0.155%; S 0.010%; As 0.19-0.20%; Fe 0.27-0.38%; Sb 0.20-0.48%; Ni 0.16-0.33%; Ag 0.04-0.09%; Au 0.17-0.19%
Beta phase: Cu 74.41-74.83%; Sn 23.68-24.34%; Pb 0.07-0.214%; S 0.07%; As 0.03-0.21%; Fe 0.23-0.28%; Sb 0.54-0.69%; Ni 0.27-0.31%; Au 0.19-0.23%

METALLOGRAPHIC STRUCTURE:
Twinned α-phase with small areas of acicular martensite (β_1') appearing on large areas of long thin needles of β' martensite (banded martensite). The banded martensites are in the large β-grains (β_2 or γ phase).

COMMENTS: The object was cast, then heavily hot worked (as shown from the twin bands) and quenched (as shown from the martensitic structure) from a temperature above 650°C. The decoration was formed by cutting. See also 18022A and 18022B.

Hardness: H_v = 213.9 (α-phase); H_v = 389.9 (background of β_2 grains with β'-banded martensite).

CATALOGUE ENTRY

SITE: BAN NA DI

AREA: Pit:

Layer:

Depth:

LAB NO: 18008 (P 30, rim/body)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 771-774

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a container, rim and part of body. Polished outer surface, rough inside surface. Corroded on the surface.

DIMENSIONS AND WEIGHT:

thickness: 1.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 70.004%; Sn 22.198%; Pb 0.291%; As 0.037%; Sb 0.013%; Fe 0.033%; Ag 1.230%
Total 93.798%

METALLOGRAPHIC STRUCTURE:

Well developed dendritic α-phase in needle matrix of β_1'-martensite.

COMMENTS·

The object was cast, briefly annealed, and quenched. The quenching temperature should be in the range of 798°-586°C. The dendrites were large.

Hardness: H_v = 22.7 (β-phase); H_v = 187.9 (dendritic area)

CATALOGUE ENTRY

SITE: BAN DON TA PHET AREA: Pit:

LAB NO: 18009 (P 18 box 6 Ring A) Layer:

Depth:

EXCAVATION NO:

MUSEUM NO: Plate Nos: 775

PERIOD: 1810±210 B.P.

Fig Nos:

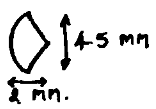
PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a ring, fairly corroded.

DIMENSIONS AND WEIGHT:

section: 4.5 x 2 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 76.436%; Sn 8.860%; Pb 10.833%; As 0.229%; Sb 0.027%;
Fe 0.006%; Ag 0.486%; Ni 0.167%
Total 97.045%

METALLOGRAPHIC STRUCTURE:

Cored α-dendritic structure with partially corroded matrix of (α+δ) eutectoid. Lead globules in interdendritic spaces.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

LAB NO: 18010 (P 18, box 6, B)

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos:

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

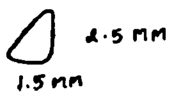
PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of a triangular section ring, fairly corroded.

DIMENSIONS AND WEIGHT:

section: 2.5 x 1.5 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 62.826%; Sn 31.254%; As 0.002%; Sb 0.059%; Fe 0.068%; Ag 0.766%
Total 94.973%

METALLOGRAPHIC STRUCTURE:

Very fine needles of β-martensite, with very small α-phase distributed in the background.

COMMENTS:

The object was cast and annealed, probably at about 750°-586°C (β'-phase range) and then quenched.

Hardness = H_v = 230.7 (martensite)

CATALOGUE ENTRY

SITE: BAN DON TA PHET AREA: Pit:

LAB NO: 18011A Layer:

EXCAVATION NO: Find no.910, burial 56 Depth:

MUSEUM NO: Plate Nos: 776 and 777

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF: Excavation at Ban Don Ta Phet, November 1980 to January 1981, A Preliminary Report, by Ian C. Glover.

DESCRIPTION: A large bucket-like container with thicker walls than other types of container. It has a ring base, flaring straight sides, two flat strap handles and a shallow, incised fishbone design in a band around the upper part. It was bent rather than split or shattered like the smaller, thin-walled bowls. In form it more closely resembles Dong-song metal types from North Vietnam than anything yet found in Thailand.

DIMENSIONS AND WEIGHT:
Rim: diameter: 21.7 cm
thickness: approx. 3 mm
Base: diameter: 13.6 cm
thickness: approx. 1-1.5 mm
Handle: thickness: 2.5 mm
Width of strap handle: 6 mm
Length of base to rim: 20.5 cm
Perpendicular height: 17.5 cm

COMPOSITION:
The sample was taken from the area under the handle.

ICP: Cu 68.147%; Sn 10.593%; Pb 21.946%; As 0.227%;
Fe 0.378%; Ag 0.388%; Ni 0.188%; Co 0.096%
Total 101.964%

COMMENTS:
The same as 18011 B.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18011 B

EXCAVATION NO: Find no.910, burial 56

MUSEUM NO:

Plate Nos: 776-784

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF: Same as 18011 A.

DESCRIPTION: Same as 18011A. The sample was taken from the base.

DIMENSIONS AND WEIGHT:

The same as 18011A

COMPOSITION: (XRF; EPMA; AA; ICP)
The sample was taken from the base.)
ICP: Cu 44.461%; Sn 7.170%; Pb 13.254%; As 0.096%; Fe 0.379%;
Ag 0.105%; Ni 0.098%; Co 0.040%;
Total 65.604%

METALLOGRAPHIC STRUCTURE:

Cored α-dendritic structure in the interdendritic eutectoid phase. There are a lot of large and medium sized casting cavities distributed over the sample. There are also black lead globules distributed throughout the specimen.

COMMENTS:

The object was cast by the lost wax process in one piece, including the handles, and the incised decoration was formed as a part of the casting.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18012 (P7)

EXCAVATION NO:

MUSEUM NO: 530/2519

Plate Nos: 785-787B

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION:

A fragment of a container; metal sound. The decorations are incised.

DIMENSIONS AND WEIGHT:

thickness: approx. 0.7 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Cu 79.7%; Sn 20.3%. Trace elements: Fe, Co, Ni, Bi, Ag.

METALLOGRAPHIC STRUCTURE:

Twinned α-phase, with small areas of β_1'-martensite and large areas of long thin needles of β'-martensite (banded martensite). The banded martensite appears in the background of large β-grains (β_2 or γ phase).

COMMENTS:

The object was cast, then heavily hot worked and quenched from a temperature above 650°C.

Hardness: H_v=225.6 (β'-martensite area); H_v=166.5 (α-phase with background contribution).

CATALOGUE ENTRY

SITE: BAN DON TA PHET AREA: Pit:

LAB NO: 18013 (P 18, box 2, rim) Layer:

Depth:

EXCAVATION NO:

MUSEUM NO: Plate Nos: 788 and 789

PERIOD: 1810±200 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A rim of a container.

DIMENSIONS AND WEIGHT:

thickness: 0.5 x 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

α-dendritic phases with needles of β_1' martensite in between.

COMMENTS:

The object was cast, briefly annealed, and quenched from the temperature range of 798°-586°C. The β_1' martensite appears in a small amount due to the low tin content.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18014 (P24)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 790

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment from a bowl of hemispherical shape.

DIMENSIONS AND WEIGHT:

thickness: 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: (qualitative analysis): Cu; Sn and trace element Co.

ICP: Cu 73.69-75.43%; Sn 20.21-21.42%; Pb 0.02-0.22%; S 0.010-1.58%; As 0.05-0.143%; Fe 0.08-0.24%; Sb 0.04-0.43%; Ni 0.01-0.08%; Ag 0.16-0.43%; Au 0.09-0.44%; Zn 0.08-0.19%

METALLOGRAPHIC STRUCTURE:

The structure consisted of β-martensite (β_1') only.

COMMENTS:

The object was cast and quenched from the β-region. The tin content of this sample should be around 25 wt% tin, and quenched from about 700°C.

Hardness: H_v = 228.0

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18015 (P25)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 791

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a square section bracelet.

DIMENSIONS AND WEIGHT:

section: 3 x 3 mm.

COMPOSITION: (XRF; EPMA; AA; ICP)

SRF (qualitative analysis): Cu; Sn; Pb. Trace element: Ni.

METALLOGRAPHIC STRUCTURE:

α-phase with a lot of lead globules distributed all over the specimen. There are also a lot of casting cavities. There is no trace of dendrites.

COMMENTS:

The object was cast and annealed.

Hardness: $H_V = 80.3$

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18016A (P22 spoon)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 792 and 793

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: An incomplete ladle. There is metal core left. The section was cut from the bowl.

DIMENSIONS AND WEIGHT:

thickness: 0.5-2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Cu 74.55%; Sn 25.45%; trace element: Co

METALLOGRAPHIC STRUCTURE:

Small twinned partly rounded α-phase in the needle-like matrix of β_1'-martensite, with some small amounts of features which look like banded martensite (β').

COMMENTS:

The object was cast and slightly hot worked, and quenched from the temperature range of the (α+β) region, 798^{o}-586^{o}C.

Hardness: H_v = 278.1 (β_1'-martensite)
H_v = 223.1 (α-phase with some martensite)

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18016B (P29 handle)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 794-796

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: Ladle handle, corroded in some parts. The section was taken from the handle.

DIMENSIONS AND WEIGHT:

thickness: 2.5 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Cu 74.55%; Sn 25.45%; trace element: Co

METALLOGRAPHIC STRUCTURE:

The structure consisted of twinned α-phase in an unresolved background with banded martensite (β').

COMMENTS:

The object may have been cast and hot worked, then annealed and quenched from the ($\alpha+\beta_1$) region. It should have been cast in one piece together with the ladle bowl.

Hardness: H_v=283.2

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18017 (P33, rim)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 797 and 798

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a rim of a container, very corroded.

DIMENSIONS AND WEIGHT:

thickness: 3 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Equiaxial grain structure, with plates of (probably) α-phase precipitated in darker (α+δ) eutectoid.

COMMENTS:

The object was cast and annealed.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18018 (P38)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 799

PERIOD: 1810±200 AD

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a bracelet.

DIMENSIONS AND WEIGHT:

thickness: 1 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Pb

METALLOGRAPHIC STRUCTURE:

α-dendritic structure in the matrix of corroded phases of (α+δ) eutectoid and segregated lead.

COMMENTS:

The object was cast.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18019 (P43 lid)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 800-804

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: Base of a container, corroded in some areas, conical boss in centre.

DIMENSIONS AND WEIGHT:

height: 1.8 cm
width: 4.8 cm

base of cone: 1 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Small twinned α-phase in very fine needles of β_1'martensite. The only sound metal in this object was at the surface, suggesting inverse segregation or uneven quenching.

COMMENTS:

It was cast, then slightly worked in the hot state, then heated up to the temperature range of the (α+β) region and quenched.

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18020 (P48)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 805 and 807

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment from a container (shape uncertain) corroded on the surface.

DIMENSIONS AND WEIGHT:

thickness: 0.6 cm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Cu 70.55%; Sn 29.55%. Trace element: Co

METALLOGRAPHIC STRUCTURE:

Small twinned α-phase in needle structure of β_1'-martensite.

COMMENTS:

The object was cast, slightly worked in the hot state, annealed to the temperature of the (α+β) range, and quenched.

Hardness: H_v = 223.8 (martensitic area)

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

LAB NO: 18021A (P61 rim)

Layer:

Depth:

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 808 and 809

PERIOD: 1810±210 B.P.

Fig Nos:

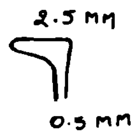
PRESENT LOCATION:

EXCAVATION REF:

DESCRIPTION: A fragment of the rim of a container (unidentified shape).

DIMENSIONS AND WEIGHT:

thickness: 0.5 - 2.5 mm



COMPOSITION: (XRF; EPMA; AA; ICP)

ICP: Cu 77.22%; Sn 22.7%. Trace elements: Fe, Pb.

METALLOGRAPHIC STRUCTURE:
Islands of α-phase on a background of β_2 grains (β_1 or γ phase)with a mixture of banded martensite (β') and very small areas of acicular martensite (β_1') are in the gray background of β_2 grains.

COMMENTS:

The object might have been cast, then heated up to the $(\alpha+\beta_1)$ region (586^{o}-520^{o}C) and quenched.

Hardness: H_v = 256.9 (background)
H_v = 206.8 (α-phase and some part of the background)

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18021B(P61 container)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 810-811

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a container (waisted beaker shape).

DIMENSIONS AND WEIGHT:

thickness: 0.4 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

METALLOGRAPHIC STRUCTURE:

Twinned α-phase and non-twinned plates of α-phase on a background of probable β_2 grains (β_1 or γ phase). In some areas there is banded martensite (β') on the gray β_2 background.

COMMENTS:

The object was cast, then slightly hot worked and heated up to the ($\alpha+\beta_1$) region (586°-520°C) and quenched. (See also 18021A).

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18022A (530/215, circular decoration)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 812-816

PERIOD: 1810±210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a rim of a container (thick bowl). Metal sound. Decorated. Sectioned through the "dot and circle" decoration. (See also 18007, from the same object.)

DIMENSIONS AND WEIGHT:

thickness: 1.5-2 mm

COMPOSITION: (XRF; EPMA; AA; ICP)

XRF: Cu 71.2%; Sn 28.8%. Trace element: Co

See also 18007 (P5 or P6, rim).

METALLOGRAPHIC STRUCTURE:

Twinned α-phase with small areas of acicular martensite (β_1') appearing on large areas of long thin needles of banded martensite (β'). The banded martensite is in the large β-grains (β_2 or γ phase). There is no evidence of deformation by working on the decorated area.

COMMENTS:

The object was cast, then hot worked and quenched from a temperature in the ($\alpha+\beta_1$) region or higher. The decoration was formed by cutting. (See also 18007 and 18022B.)

Hardness: H_v = 213.9 (α-phase)
H_v = 389.9 (background area of β_2 and banded martensite)

CATALOGUE ENTRY

SITE: BAN DON TA PHET

AREA: Pit:

Layer:

Depth:

LAB NO: 18022B (530/215, line decoration)

EXCAVATION NO:

MUSEUM NO:

Plate Nos: 817-821

PERIOD: 1810$\pm$210 B.P.

Fig Nos:

PRESENT LOCATION: Bangkok National Museum

EXCAVATION REF:

DESCRIPTION: A fragment of a rim of a container (thick bowl). Metal sound. Decorated. Section through the line decoration.

DIMENSIONS AND WEIGHT:

As for 18022A.

COMPOSITION: (XRF; EPMA; AA; ICP)

As for 18022A.

METALLOGRAPHIC STRUCTURE:

As for 18022A.

COMMENTS:

As for 18022A.

Summary of the types of artifact from KOK KHON

Type of Artifact	Qty	Object number
Container	8	1001, 1006, 1009, 1013, 1014, 1015, 1018B, 1021
Bracelet	17	1004, 1010, 1011, 1016, 1017, 1020A, 1023, 1026, 1027A, 1027B, 1027C, 1029, 1030, 1031, 1032, 1033, 1034
Ring	1	1008
Pointed Tool (or weapon)	1	1005
Cutting Tool	1	1028
Ornament (wound thin wire)	1	1007
Ornament (wound thick helix strip)	5	1019, 1024, 1025, 1018A, 1020B
Ornament (unidentified) (a cast false wire helix)	1	1022
Unidentified object	1	1012

Summary of the types of artifact from NON CHAI

Type of Artifact	Qty	Object number
Bracelet	35	1101, 1102, 1103, 1104, 1105, 1106, 1109, 1111, 1113, 1114, 1115, 1118, 1120, 1121A, 1121B, 1123, 1124, 1125, 1127, 1128, 1129A, 1129B, 1129C, 1130, 1131A, 1131B, 1133, 1134, 1135A, 1135B, 1136A, 1136B, 1137, 1145A, 1145B
Bracelet with bell	1	1116
Ring	5	1107, 1108, 1110, 1112, 1119
Bell	7	1117, 1138, 1139, 1140, 1142A, 1142B, 1143
Fragment of Bronze	1	1132

Summary of the types of artifact from MISCELLANEOUS SITES

Types of Artifact	Qty	Object number
Ring	7	1901A, 1901B, 1901C, 1901D, 1901E, 1902C, 1902D
Bracelet	29	1901F, 1901G, 1902E, 1903, 1904A, 1904B, 1904C, 1905B, 1905C, 1906A, 1906B, 1907, 1908, 1909, 1910, 1911, 1912A, 1912B, 1912C, 1912E, 1912D, 1912F, 1912G, 1912H, 1913A, 1913B, 1913C, 1914A, 1914B
Bead	1	1902A
Container	2	1902F, 1902G
Cutting tool	1	1905A
Kettle drum	4	1915A, 1915B, 1915C, 1915D

Summary of the types of artifacts from NON NOK THA

Types of Artifact	Qty	Object number
Bracelet	52	15001, 15002, 15003, 15004, 15005, 15006, 15007, 15008, 15009, 15010, 15011, 15012, 15013, 15014, 15015, 15016, 15017, 15019, 15023, 15032, 15033, 15039, 15040, 15042, 15050, 15052, 15053, 15054, 15057, 15058, 15059, 15060, 15061, 15062A, 15062B, 15063, 15064, 15065, 15066, 15067, 15069, 15070, 15073, 15074, 15076, 15077, 15078, 15079, 15080, 15082, 15083, 15084
Ring	2	15051, 15071
Ring (earring?)	1	15055
Cutting tool (axe)	2	15022, 15047
Pointed tool or weapon (arrowhead)	1	15018
Fragments	8	15021, 15029, 15030, 15031, 15038, 15046, 15081, 15116
Lump or spillage	61	15020, 15024, 15025, 15026, 15027, 15028, 15043, 15044, 15045, 15048, 15056(ABCDEF), 15072, 15075(ABCDE), 15085(AB), 15086(AB), 15087, 15088, 15089, 15090, 15091(AB), 15092, 15093, 15094, 15095, 15097, 15098(ABC), 15099, 15104, 15105, 15106, 15107, 15108(AB), 15109(AB), 15110, 15111(ABC), 15112, 15113, 15114, 15115, 15117, 15118(ABC)
Droplet	11	15035, 15036(AB), 15037, 15041, 15049, 15096, 15100, 15101, 15102, 15103
Unidentified object	1	15068

Summary of the types of artifact from BAN NA DI

Types of Artifact	Qty	Object number
Cutting tool	5	16001, 16003, 16007, 16008, 16009
Arrowhead (pointed)	1	16010
Bracelet	44	16006, 16012, 16013, 16014, 16015, 16016, 16017, 16018, 16019, 16020, 16021, 16024, 16025, 16026, 16027, 16028, 16030, 16031, 16033, 16036, 16040, 16042, 16044, 16045, 16046, 16047, 16048, 16049, 16050, 16052, 16055, 16059, 16060, 16061, 16062, 16063, 16064, 16065, 16066, 16067, 16068, 16069, 16070, 16071
Ring	12	16022, 16023, 16037, 16038, 16039, 16041, 16051, 16053, 16054, 16056, 16057, 16058
Other ornaments	3	16002, 16005, 16032
Unidentified object (ornament or tool)	4	16004, 16029, 16034, 16043
Other metal (pewter?)	1	16011
Bronze lump or casting spillage	8	16072, 16073, 16074, 16075, 16076, 16077, 16078, 16079

Summary of the types of artifact from BAN DON TA PHET

Types of Artifact	Qty	Object number
Container	11	18006A, 18006B, 18007, 18008, 18012, 18013, 18014, 18017, 18019, 18020, 18021A, 18021B, 18022A, 18022B
Bracelet	5	18001, 18002, 18003, 18015, 18018
Ring	2	18009, 18010
Bell	2	18004, 18005
Ladle	1	18016 (A=spoon, B=handle)
Bucket	1	18011 (A=handle, B=base)

6. CONCLUSIONS

6.1 RAW MATERIALS

As we have seen, no early mining sites have so far been excavated in Thailand, although a recent survey has shown an ancient copper mine, of uncertain date, in Lopburi Province (I.C. Glover, 1983, private communication).

Mineral resources known at the present day are summarized by Tantisukrit (1978); their locations are shown on the map (Fig. 8). Although copper minerals are widespread, they are not as yet commercially mined in Thailand. Chalcopyrite, chalcocite, azurite, malachite, cuprite, and native copper are all recorded.

Although tin has only been mined during the present century, it occurs extensively in the form of cassiterite, and there was certainly ancient mining in the peninsular area. Tin also occurs in many other parts of Thailand, as shown on the map (Fig. 8). With relation to the high-tin bronzes from Ban Don Ta Phet, it is interesting that the granite range along the Thai-Burmese border is rich in tin, as exemplified by the Pelox mining district in Kanchanaburi Province.

Lead and zinc deposits are also widespread, and although we have no evidence of zinc utilization in antiquity, at least before the medieval period, there would have been numerous possible sources for the lead used in many of the bronzes.

In the absence of geological samples, it is not feasible to comment even in a very general way on any possible correlation between metal composition and source materials,

แหล่งที่มาของข้อมูลจะปรากฏอยู่ตอนท้ายของแผนที่เล่ม

Sources at the end of the atlas

แผนที่นี้จัดทำขึ้นโดยกรมแผนที่ทหาร 2521
Published by Royal Thai Survey Department 1978

Fig. 8

but it is possible to make a few inferences concerning the types of ore used.

Sulphur was found, in the form of sulphide inclusions, in quite a number of objects which were examined by the electron microprobe.

This strongly suggests the use of ore of at least partly sulphidic character, probably chalcochite or chalcopyrite, and this is not inconsistent with information regarding the use of sulphide ore at the same period in the Near East.

The extremely small number of objects of pure copper, free from any significant amount of tin, is rather more surprising, because of the abundance of tin, and the greater ease of working tin bronzes as opposed to pure copper makes any resource to copper artifacts almost unnecessary.

Quite apart from the intentionally leaded bronzes, almost all the artifacts examined contain a significant concentration of lead, and it appears that anything up to one and a half per cent of lead would appear in the metal as extracted and refined. This must also reflect the type of mineralization, although it is not significantly larger than that found in many parts of the world.

The distribution of trace elements excluding those mentioned above does not vary significantly for the sites of North-East Thailand, although there is a clear differentiation between these artifacts and the artifacts from Ban Don Ta Phet. It may relate to differences in ore sources, as yet there is not sufficient data to confirm this.

Table 9. Mean value of trace elements in artifacts from different sites in Thailand.

Site	Mean value in % of elements						
	As	Sb	Fe	Ag	Ni	Co	Bi
Kok Khon	0.157	0.132	0.107	0.094	0.035	0.0046	0.014
Non Chai	0.234	0.162	0.248	0.101	0.0234	0.006	0.016
Non Nok Tha	0.247	0.118	0.130	0.118	0.021	0.004	0.022
Ban Na Di	0.141	0.036	0.257	0.140	0.007	-	0.021
Ban Don Ta Phet	0.093	0.023	0.219	0.624	0.062	0.0065	-

6.2 EXTRACTION PROCESSES

There is at present no evidence for ancient smelting sites in Thailand, and the metallurgical waste which has been discovered does not seem to relate to smelting processes. Most of the artifacts contain iron, frequently in the metallic state, in levels consistent with that in other smelted copper from South and South-East Asia. This is purely an indication of reducing conditions. The iron itself may be derived from the ore, the iron oxide flux, or impurities in the charge.

6.3 ALLOYING

The histograms of the tin and lead content of the artifacts analysed (Fig. 9-20) give a good indication of the type and composition range of the alloys used. The histograms are both for the material as a whole, and for artifacts from individual sites.

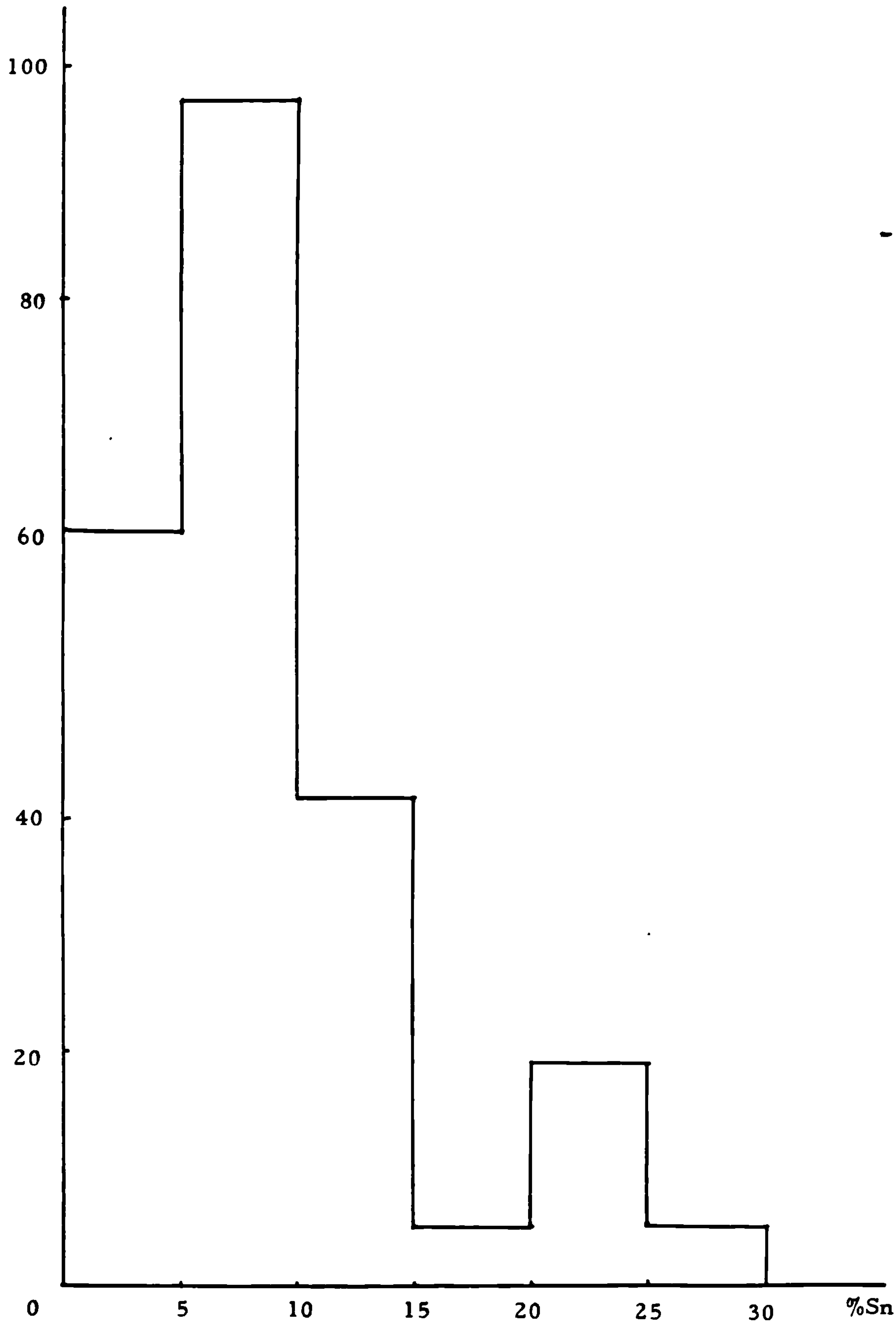


Fig. 9 Histogram of tin content for all sites

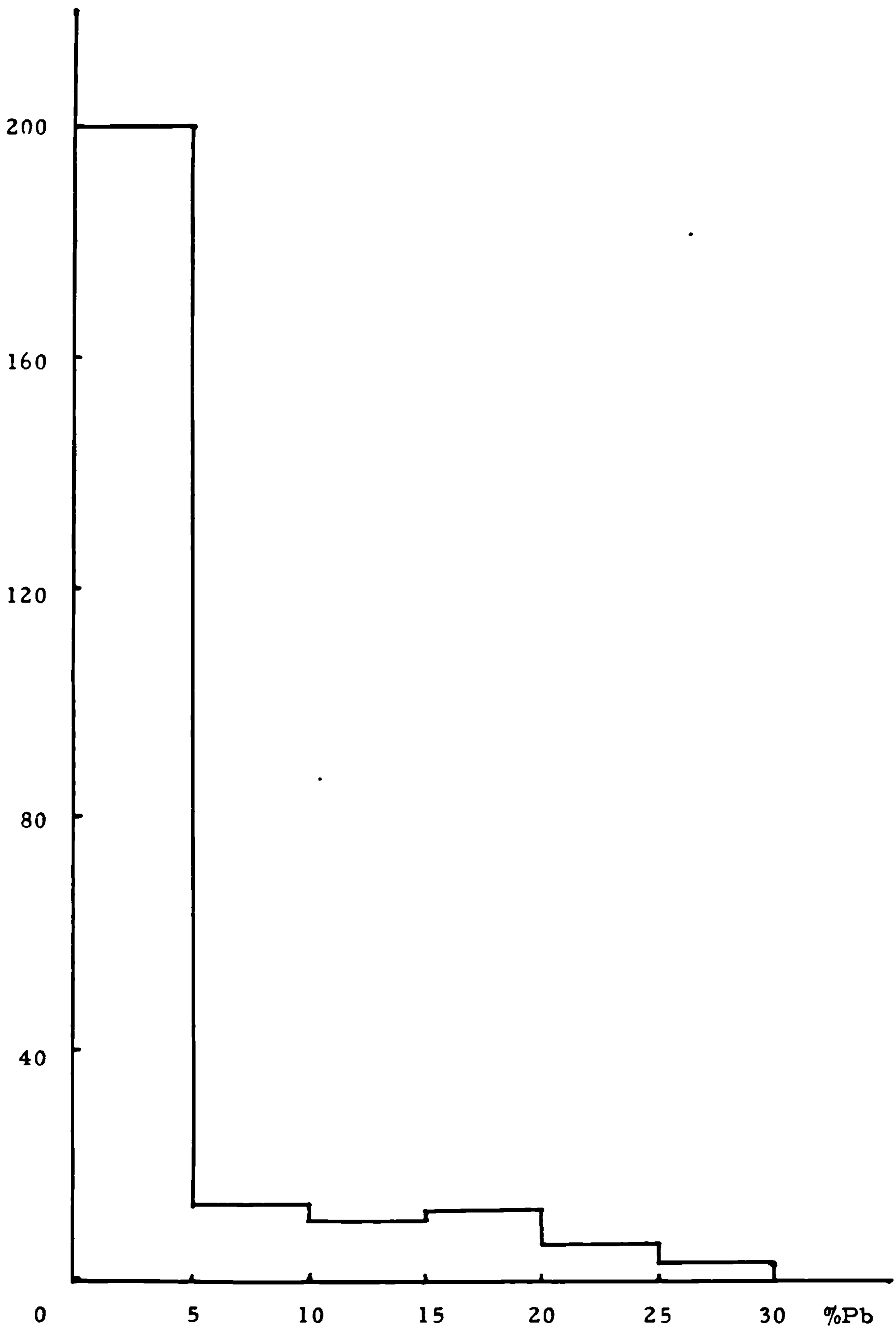


Fig. 10 Histogram of lead content for all sites

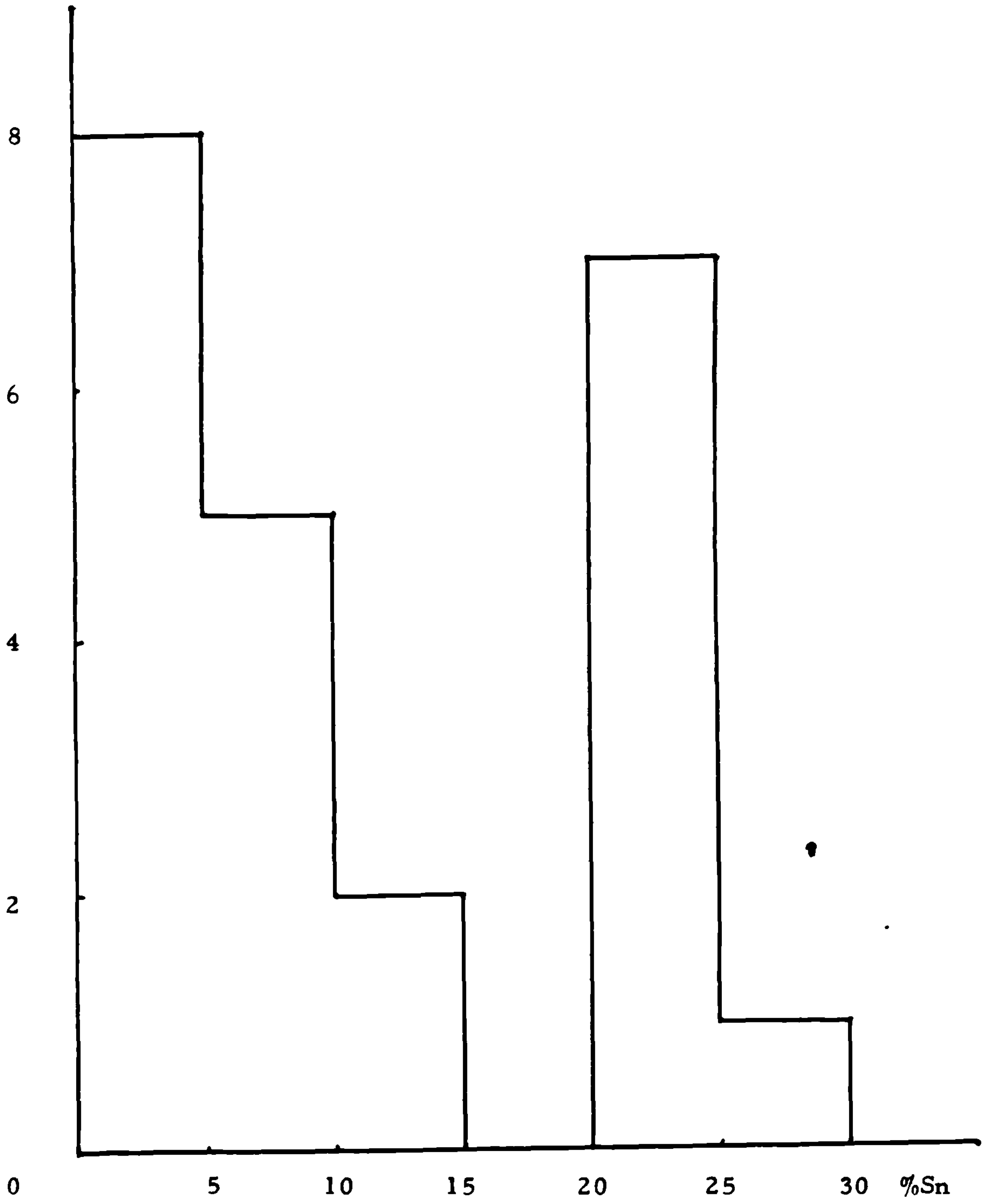


Fig. 11 Histogram of tin content of samples from Kok Khon

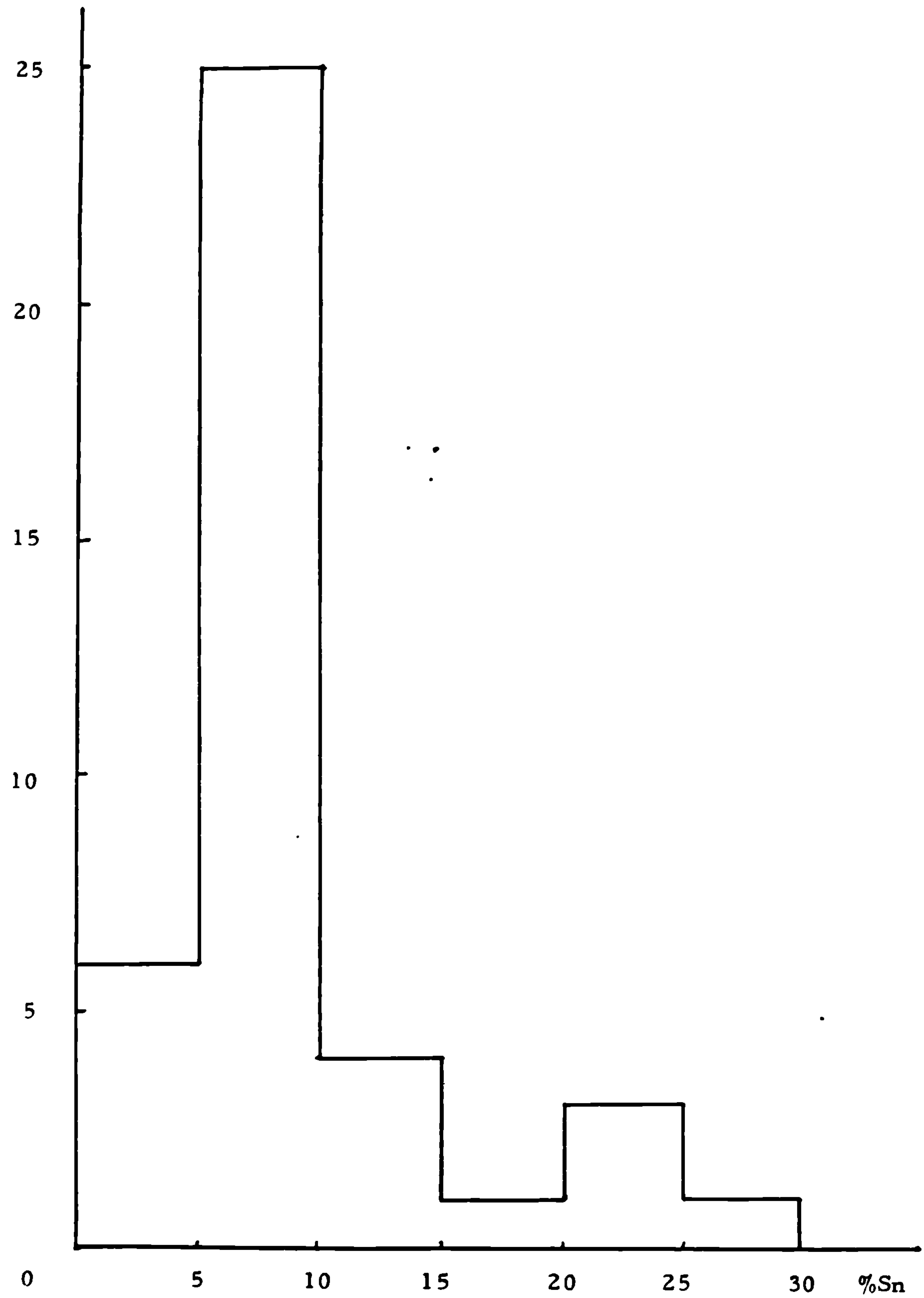


Fig. 12 Histogram of tin content of samples from Non Chai

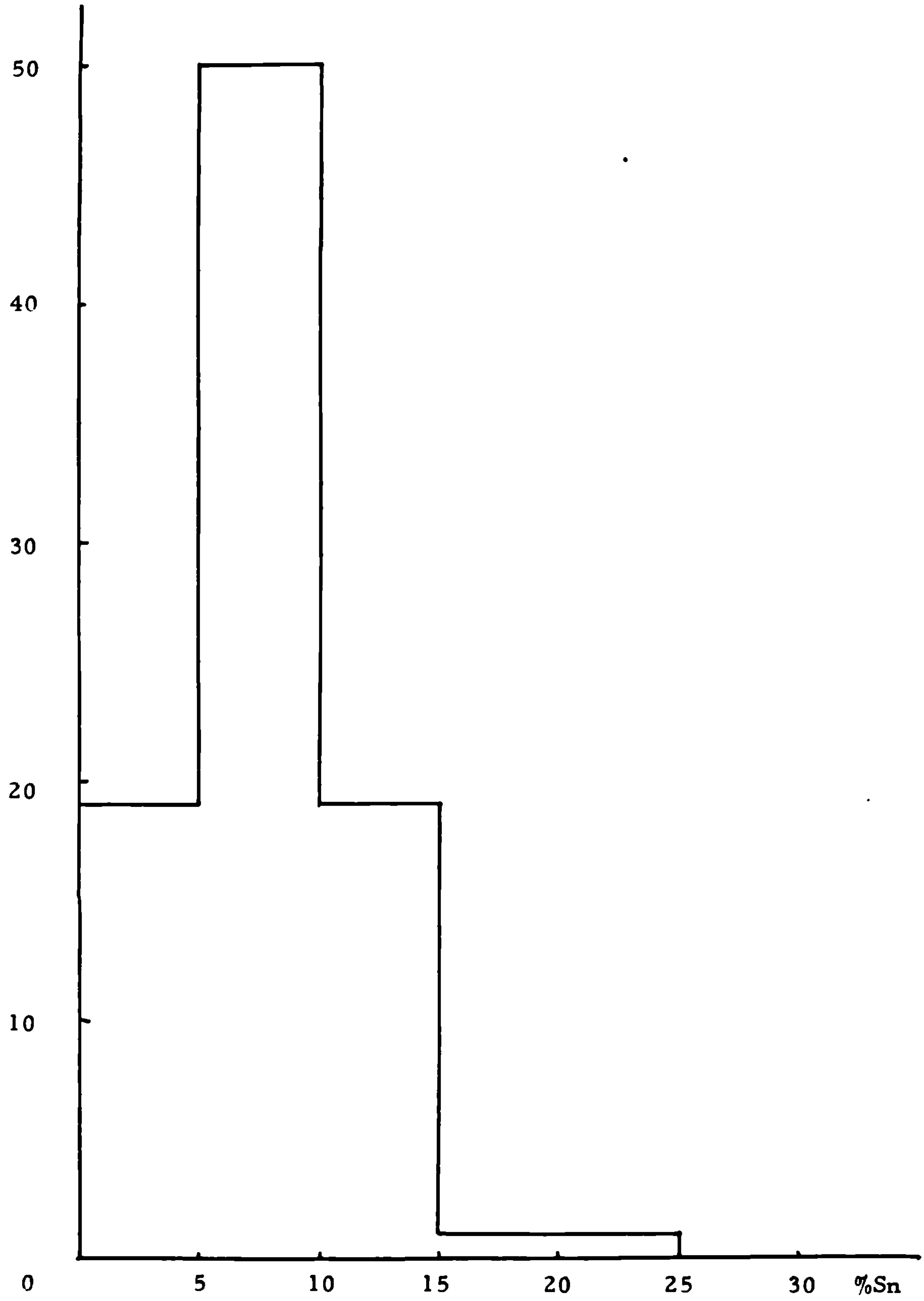


Fig. 13 Histogram of tin content of samples from Non Nok Tha

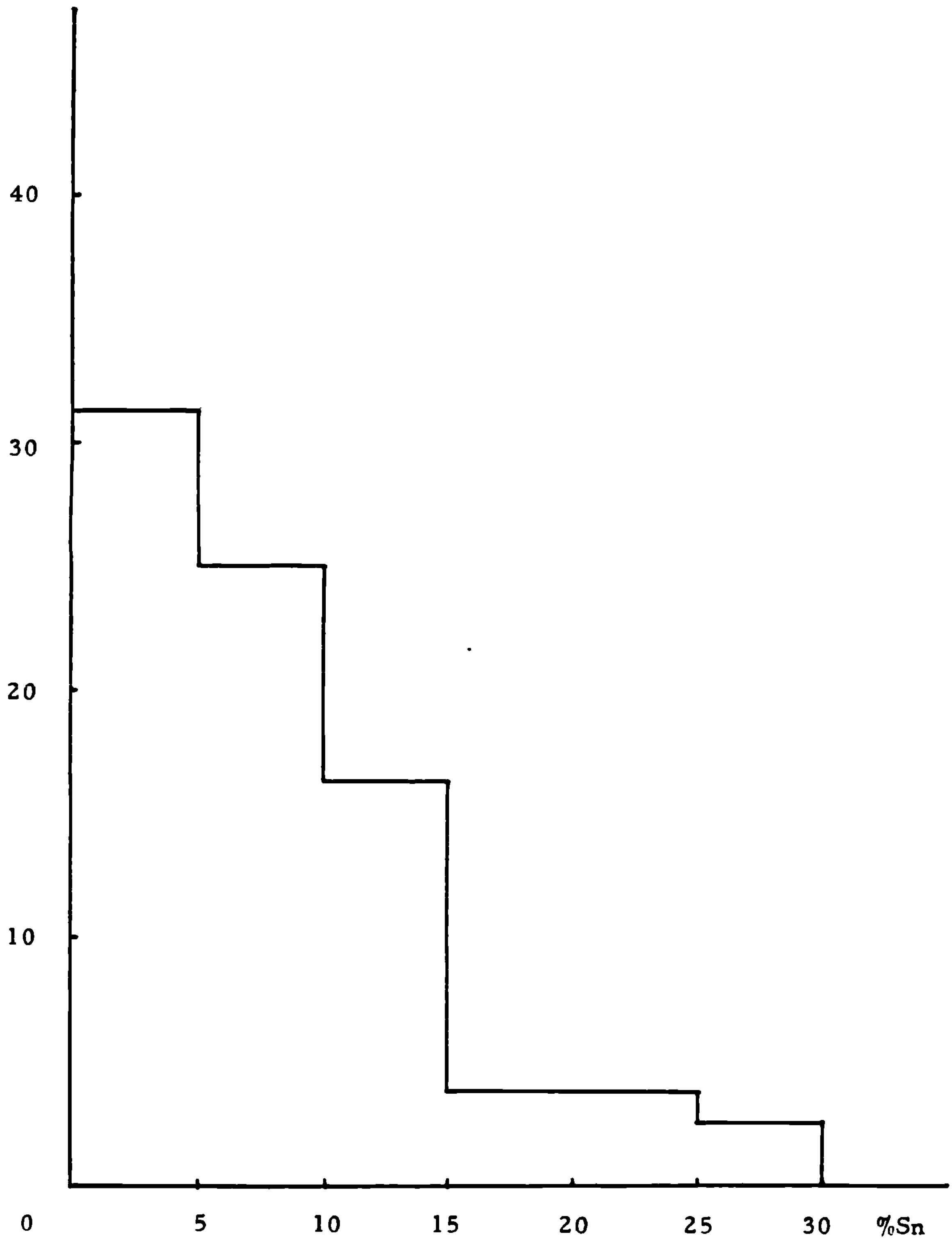


Fig. 14 Histogram of tin content of samples from Ban Na Di

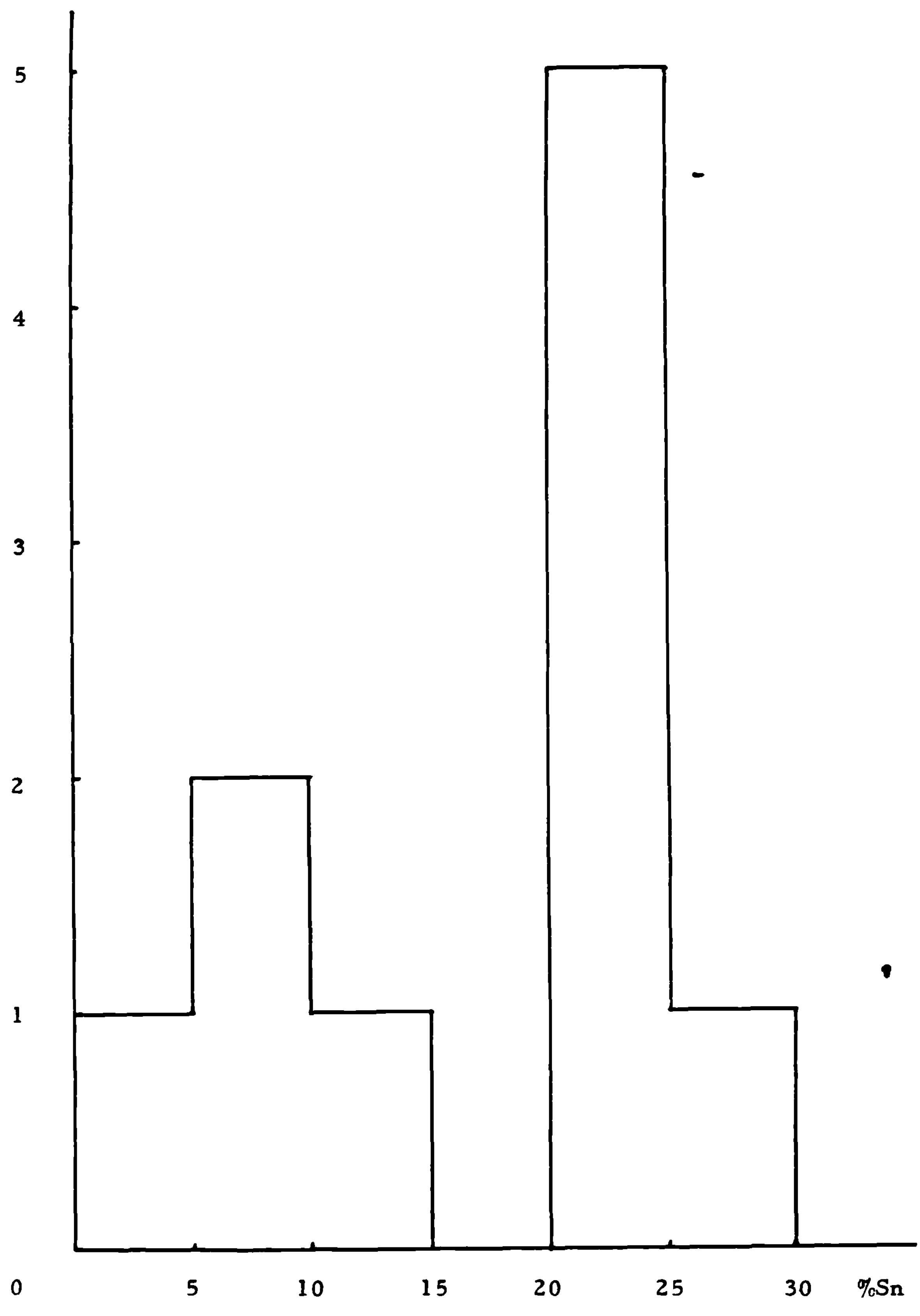


Fig. 15 Histogram of tin content of samples from Ban Don Ta Phet

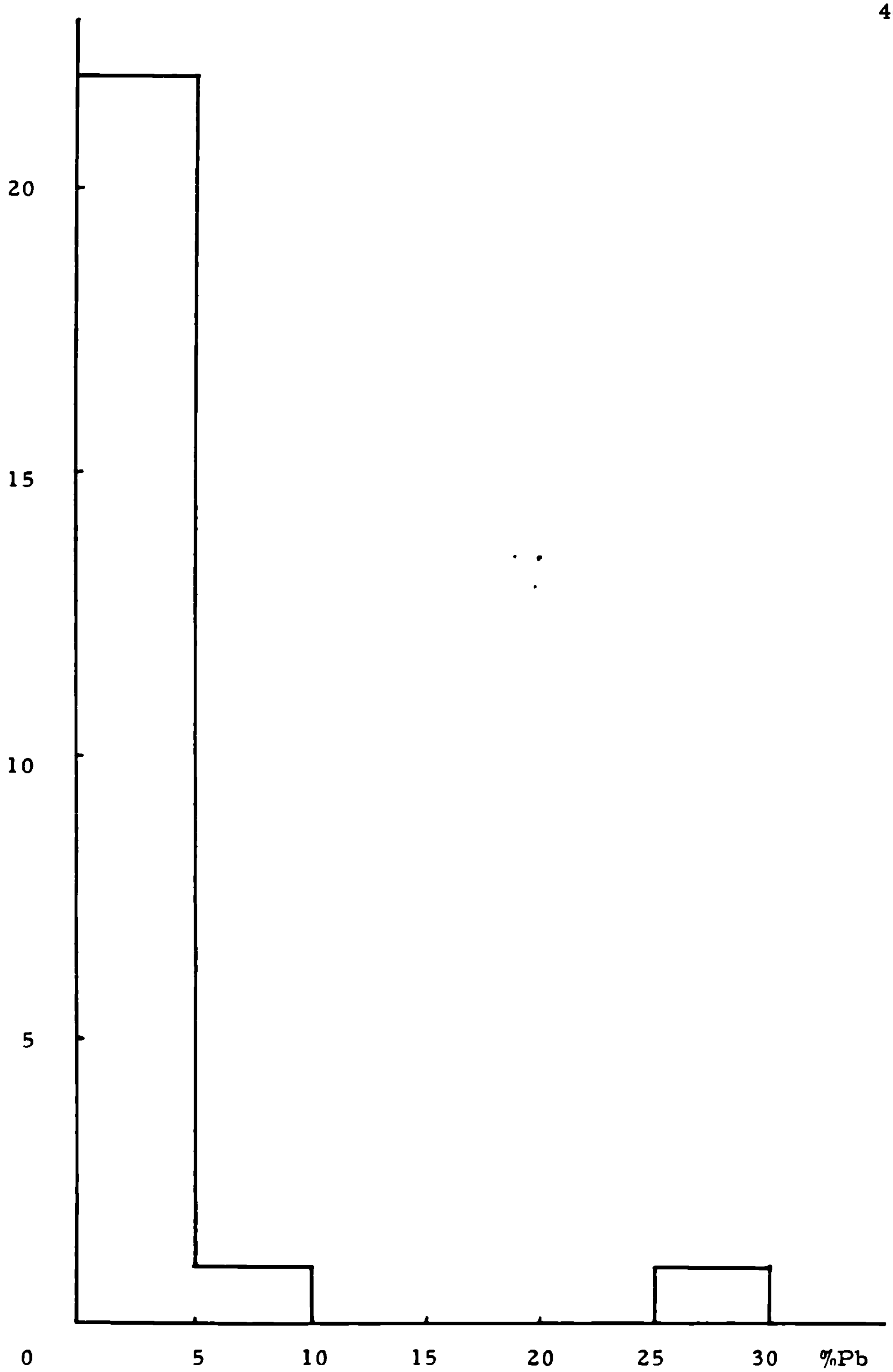


Fig. 16 Histogram of lead content of samples from Kok Khon

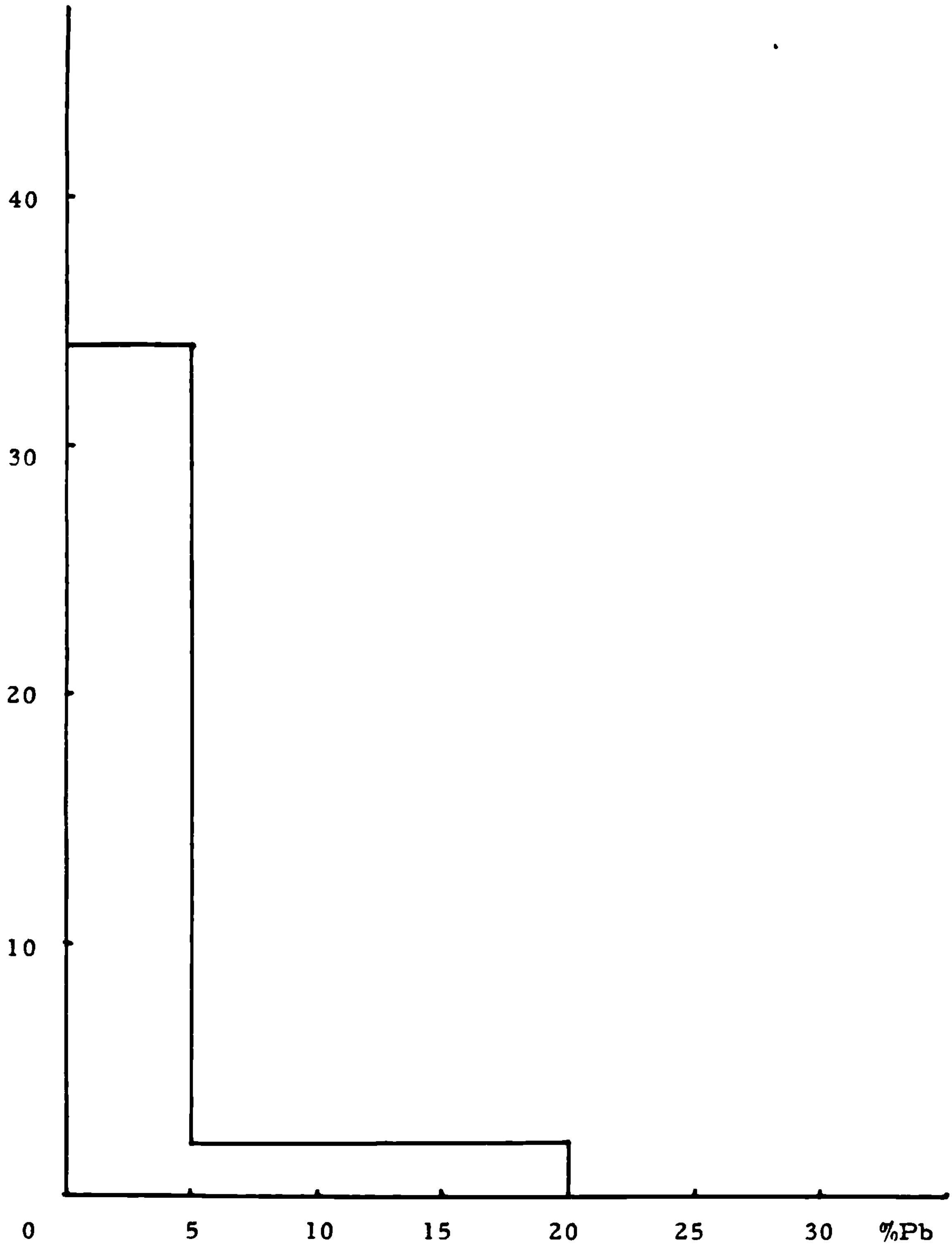


Fig. 17 Histogram of lead content of samples from Non Chai

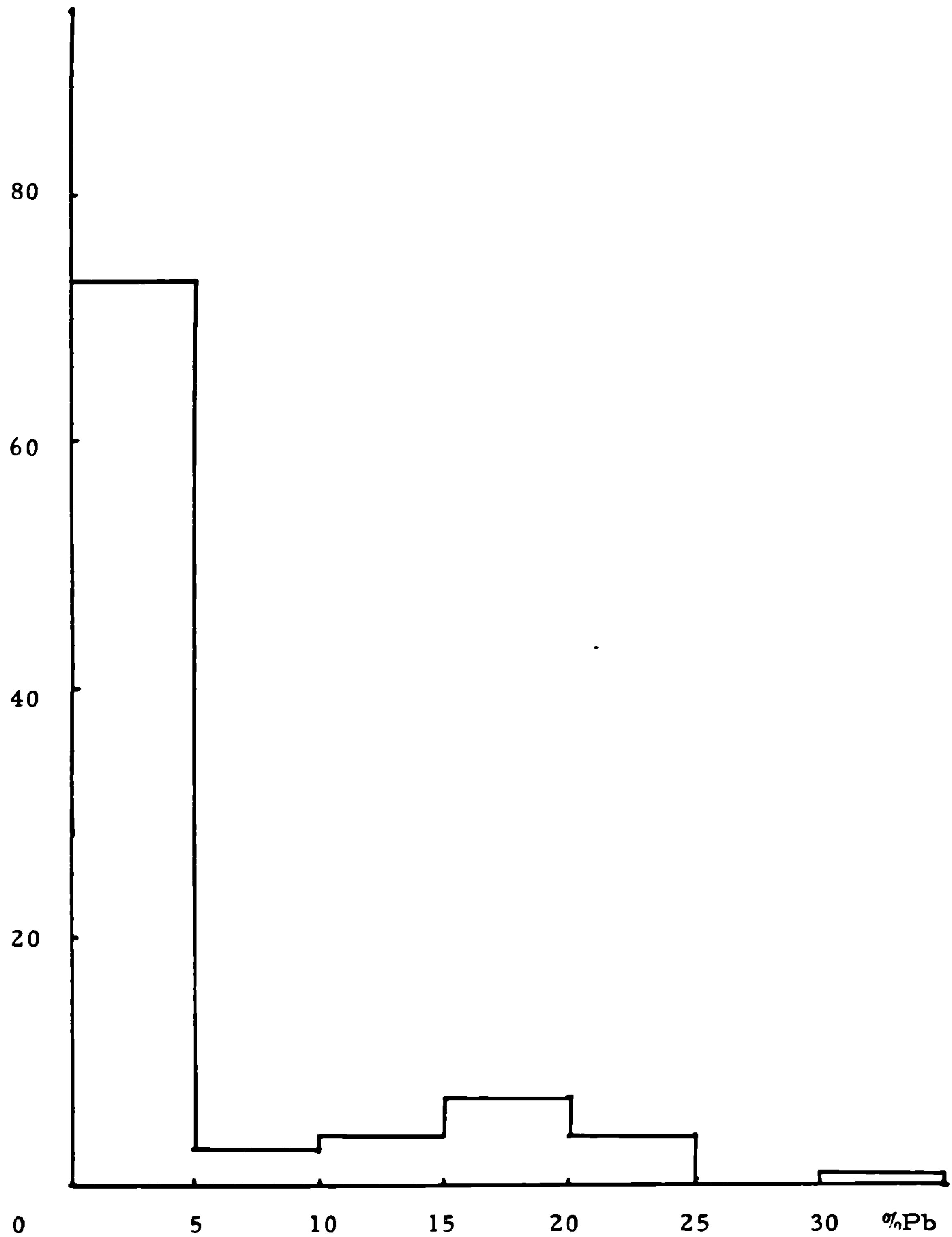


Fig. 18 Histogram of lead content of samples from Non Nok Tha

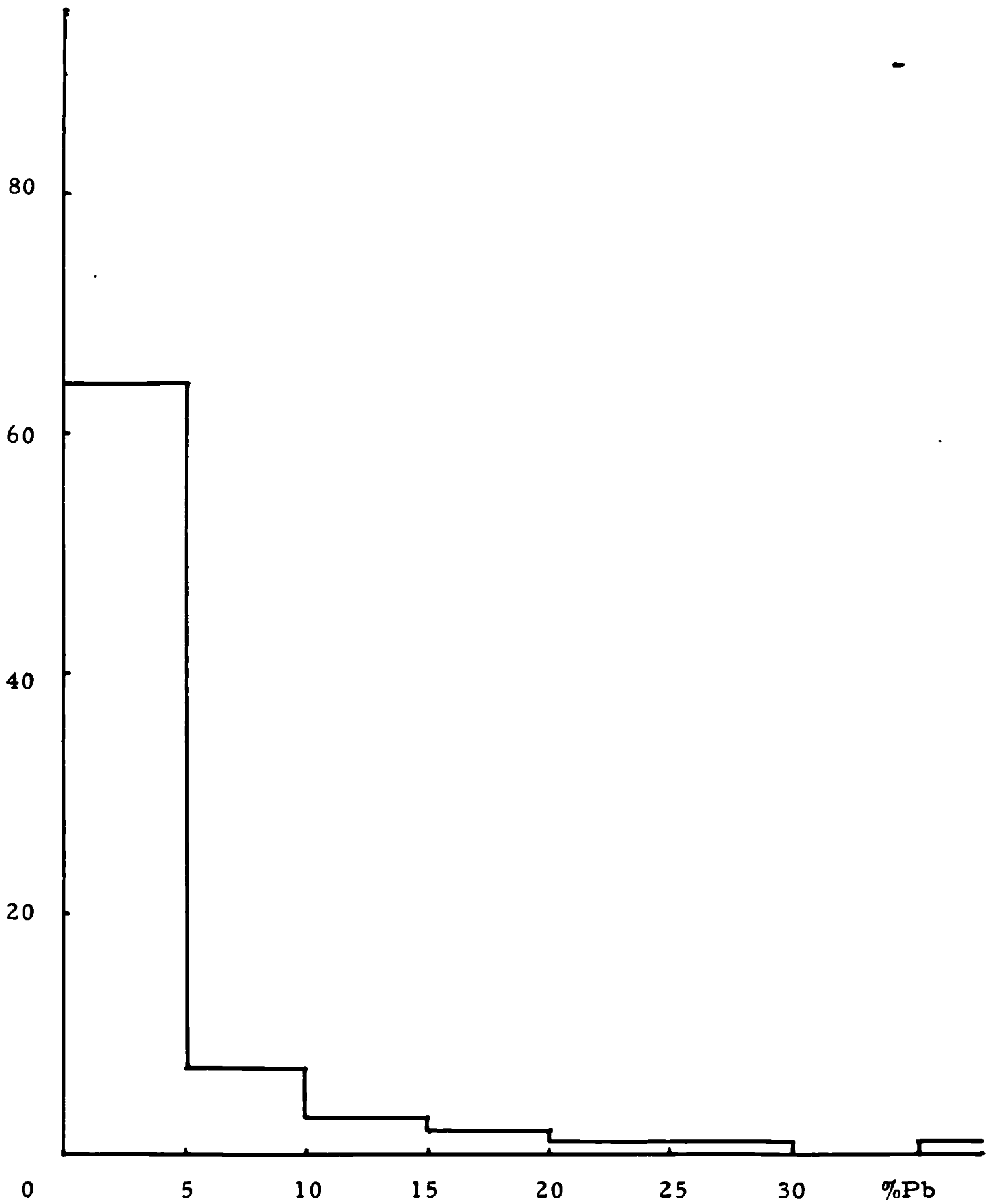


Fig. 19 Histogram of lead content of samples from Ban Na Di

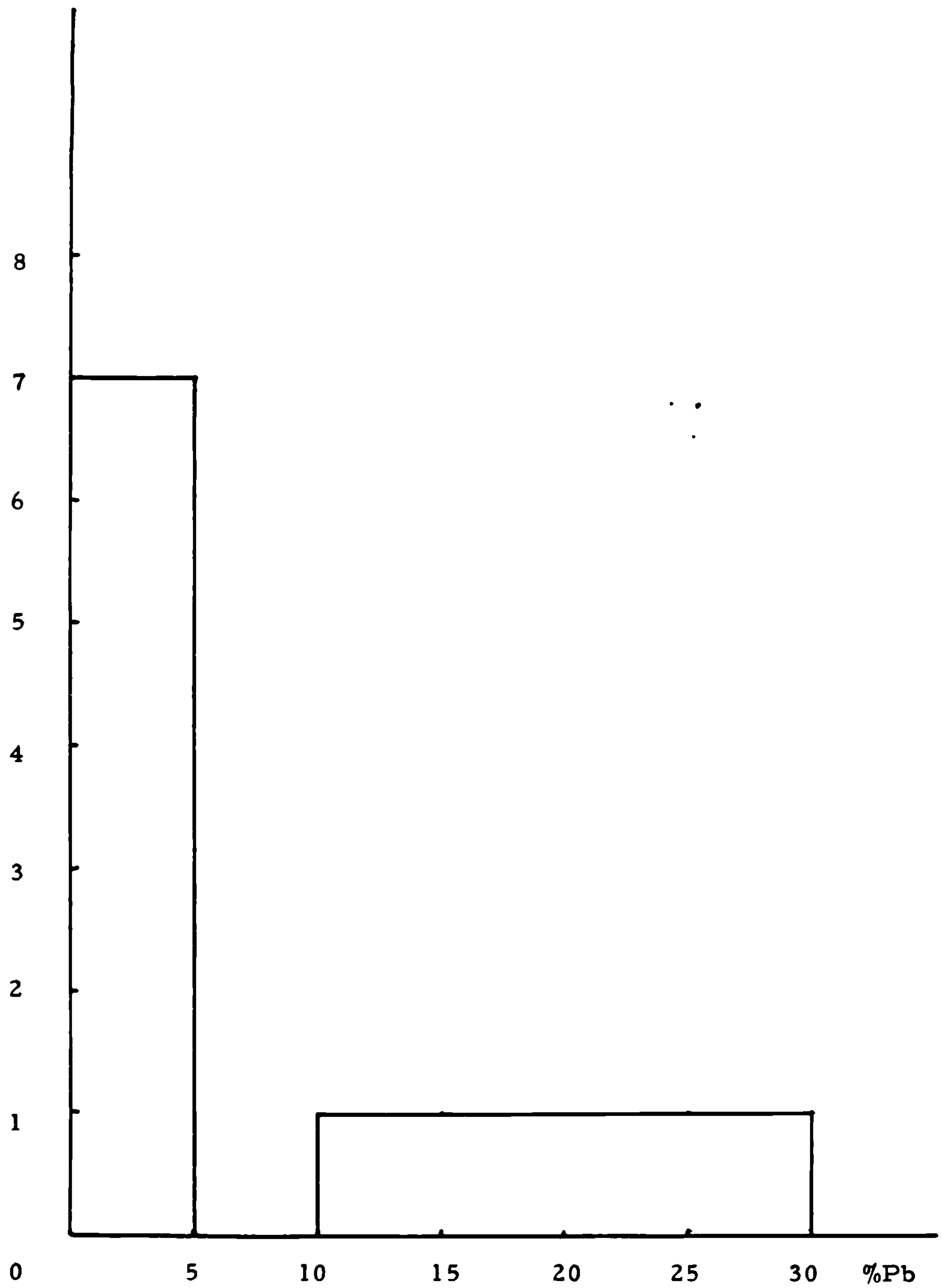


Fig. 20 Histogram of lead content of samples from Ban Don Ta Phet

6.3.1 Pure copper

The only object analysed which proved to be free of both tin and lead was a fragment from Non Nok Tha (15081), provisionally dated to 2300 B.C. It is possible that alloying was carried on locally immediately prior to the casting process, and according to the intended function of the object.

6.3.2 Low tin bronzes

Low-tin bronzes without intentionally added lead are found very widely. They include objects of both a functional and a decorative nature. The distribution of tin contents is perfectly consistent with that used in various other parts of the world.

6.3.3 Leaded low tin bronzes

These are found in almost all the sites examined and they are, as would be expected, mainly decorative. They include some of the more complicated castings, and although lead contents of over 25% were found, most were in the region of 5-20%.

6.3.4 High tin bronzes

This highly specialized alloy is discussed in detail elsewhere in the thesis, with justification for its selection and technology. Its overwhelming occurrence at one particular site, Ban Don Ta Phet, may only be the result of chronology; the alloy did not come into use until the Iron Age, and may have only been employed for a relatively short time.

6.3.5 Leaded high tin bronzes

This alloy is represented by only one unique object, and the reason for its use is by no means clear. No.1028 was a thin socketed axe, whose construction did not fit it for practical use. The structure indicated that it was cast with no heat-treatment cr working of any sort. It is not obvious why such a ceremonial artifact should not be a normal high-tin bronze, as this is also relatively easy to cast.

6.3.6 Brass

Only one of the artifacts analysed, no.15071, from Non Nok Tha, turned out to be a copper-zinc alloy, in actual fact a leaded brass. This wire ring contains approximately 18% tin and 6% lead, but may well be of 12th century date or later, and utilizing imported material. Significant levels of zinc were not detected in other artifacts.

6.3.7 Lead-tin alloys

Several artifacts, apparently earrings, of a lead-tin alloy were obtained from the most recent excavations at Ban Don Ta Phet. These have not yet been scientifically examined.

An important object from Ban Na Di, no.16011, was a lead-tin alloy casting funnel. The tin content was approximately 24%. There are two possible explanations for the object: firstly, that it was derived from the production of lead-tin alloy decorative objects, as mentioned immediately above; secondly, that it was used as the intermediate casting material by analogy with the lost-wax process, such a technique having been suggested on several occasions before, and having been shown to have been in use in Vietnam.

6.3.8 Antimony

Only one item, no.1106, contained a significant antimony concentration in an uncorroded area of metal. In this region the antimony concentration was approximately 2%. Although antimony-containing bronzes are known from Iran and parts of Europe, they are in all probability accidental as a result of exploitation of certain types of ore, but their selection may be due to the very pale bronze which results. The effect on the microstructure is also significant but not fully explained.

6.4 FABRICATION PROCESSES

6.4.1 Metal-working remains

There is material evidence of metal casting from a number of sites in Thailand. This includes crucibles and various types of mould. Crucibles from Ban Chiang and Pimai, and a sandstone mould from Non Nok Tha were examined and published by Carriveau (1974). A clay crucible from Non Nok Tha (NP 521, MIT 295) was also studied and published by Cyril Stanley Smith (1973).

There are also fragments of ring moulds in sandstone from Non Chai (Pl.822), a pair of sandstone socketed spearhead moulds (Pl.823-824), a sandstone axe mould (Pl.825), a sandstone arrowhead mould (Pl.826) and a mould for two arrowheads (Pl.827).

Clay moulds and crucibles, together with some copper alloy artifacts, were found at Noen Klong Bamrung in Lopburi Province. Some of these artifacts are shown in Pl.828-835. These materials have not previously been published. Indirect evidence for alloying and casting operations, in the form of corroded metal droplets from Non Nok Tha and Ban Na Di in particular, is described elsewhere in this thesis.

6.4.2 Metal working techniques

6.4.2.1 Lost wax casting

A high proportion of the objects examined have been fabricated by the lost wax casting process. The great majority were solid castings, but some, particularly the larger bracelets, were cast on a core, as were of course the bells. No evidence was found for chaplets, although areas of core were left exposed in order that the clay investment would itself hold the core in position after the wax was removed. This accounts for oval or rectangular voids in a number of the objects.

One particularly interesting object, possibly unique for the area, is item number 1022, a cast false wire helix. This is an example of so-called false filigree work, so common, for example, in early South American metal casting.

A number of objects, in particular 1023, 1029, 1115, 1123, 1145B, 1906A and 16004, contain residual casting core material. These were normally gray to black in colour, and relatively hard. A sample from object 1906A was analysed using X-ray diffraction and microchemical combustion techniques. It consisted of predominately quartz and clay, with 1.1% carbon. This indicates that it is a typical clay/charcoal core, compounded from a mixture of clay and organic material, but the content of organic material was probably originally not more than about 5%, considerably lower than that commonly found from Indian and some South American metal castings. It is not dissimilar to some of the core material found in medieval Javanese bronzes.

6.4.2.2 Fabrication techniques for high tin bronzes

The results of microstructural examination and experiments on alloy manufacture have given a clear picture of the techniques used for fabricating the high-tin bronze artifacts. The first stage of the process requires the accurate formulation of the alloy, which may have been done on the basis of colour, or by weighing the alloying elements. This was then cast to produce an approximate blank for the intended object, which presented no particular problems with an alloy melting at a temperature below 900^{o}C. A few of the artifacts were then merely surface finished, but the great majority, and in particular the containers, were hot worked in the β-region, in which the metal is extremely plastic. Following the hot working process, they were quenched from the same temperature range to produce the much less brittle, tough, martensitic structure, and were then mechanically finished.

This finishing process consisted of grinding and polishing, with the addition of incised decoration where appropriate. We have evidence from the surface striations on many artifacts that the grinding and polishing were carried out using a simple lathe, as is shown in Pl.836. In spite of the considerable hardness of the metal, typically 180H_v, abrasives of the garnet or corundum variety, which were readily available in Thailand, could have been used for this process. Simple concentric line decoration was also carried out, apparently on the lathe with a hard point, and patterns of various types were added, in all probability by means of a small abrasive wheel of the type used for seal cutting, which was certainly known to have been used in the Indian sub-continent by the third century B.C. A number of items also possess dot and circle decoration which was readily achieved by using a drill with a centre point. The reason for the grinding and polishing operation was certainly to remove the hammer marks which would have resulted from the working process, and also the considerable oxide skin acquired during heat-treating and quenching.

The reason for the choice of this particular alloy has been set out in some detail elsewhere (Rajpitak and Seeley, 1979). In summary, it is likely that this is the one copper alloy available prior to the introduction of brass which exhibited a reasonable likeness to metallic gold, and within the acceptable colour range only the β-tin bronze was susceptible to fabrication. The combination of colour and working properties therefore dictated the precise alloy to be used.

6.4.2.3 Cold and hot working

A small proportion of the artifacts, mainly those of utilitarian type, exhibited a degree of hot or cold working. This appears to have been limited mainly to the cutting edges of arrowheads or similar artifacts, for the purposes of finishing, hardening or sharpening.

6.4.2.4 Wire making

Only one significant example of wire was found, no.1007 from Kok Khon. This is a coil of rectangular section wire produced by hammering down from rod or bar. It was obviously extensively worked and then annealed. Certain rings were made of thicker wire, of circular section, with no instance of any evidence of wire drawing.

6.5 ARTIFACT TYPES

The types of artifact from the different sites are analysed in Table 4. The relationship between artifact type and composition is given below.

6.5.1 Containers

The great majority of these were high-tin bronzes, fabricated in the way described above. A small number of fragments of what may have been containers also exist as leaded bronzes.

6.5.2 Personal ornaments

The simpler examples of these consisted of low-tin bronzes, and the more ornate are leaded tin bronzes. A very small percentage consisted of high-tin bronzes; these latter objects comprise rings, bracelets, and what may be necklace elements.

6.5.3 Bells

These are all leaded low-tin bronzes, produced by the lost wax casting process. Many of them have a clapper consisting of a small piece of metal or stone which was inserted in the core prior to casting.

6.5.4 Cutting tools

A number of arrowheads and axes were found, almost all comprising, as expected, low-tin bronzes. The objects were initially all cast; some were finished by working and annealing.

6.5.5 Miscellaneous objects

The bucket, item 18011, was the only leaded bronze container found. It was a lost wax casting, and it is considered to be a Dong Song import, and will not be discussed further here.

The drum fragments (no.1915) are from Tam Ongbah and are also in Dong Song style.

An unusual feature of a number of bracelets was the presence of catches. These do not previously appear to have been found at so early a date and they are rather clever in design.

6.6 CHRONOLOGY

The archaeological evidence for dating is not at this stage adequate to provide a reliable chronology for the different stages in metal technology in Thailand, nor is it possible in many cases to distinguish between chronological and regional differences. It is possible to produce a simple classification subject to the above distinction along the following lines:

1. Low-tin bronzes of a relatively simple form.

2. Leaded tin bronzes, some of the simple forms and some more complex. The use of hollow casting techniques.

3. The period during the Iron Age involving the use of quenched high-tin bronzes.

There is no evidence of a period during which copper was used unalloyed. This may reflect the adoption of bronze metallurgy from elsewhere, or the lack of materials from sufficient early sites.

There are, however, some differences in the distribution of alloys from different sites, even excluding Ban Don Ta Phet. For example, the material from Ban Na Di includes far fewer items of leaded bronze, proportionally, than that from Non Nok Tha. The regional difference is not likely to be great, and therefore may in all probability reflect the generally earlier date of Ban Na Di.

6.7 REGIONAL VARIATION

Only in the case of Ban Don Ta Phet, which is geographically quite distinct from the other sites, is it possible to seriously consider any regional variation. Differences in trace element composition have been discussed above, but the stylistic differences, and the preponderance of high-tin bronze, could equally well be explained on the basis of a very narrow chronology for Ban Don Ta Phet as opposed to the other sites. It may be purely chance that it coincides with the peak in production of bronze of this type, and also, being a cemetery site, will not necessarily be typical in the range of artifacts recovered. More information about regional variations may become apparent on the publication of the Ban Chiang material, and also as the result of excavations on sites in other areas of Thailand.

6.8 FURTHER WORK

The areas of priority in metallurgical work in Thailand are threefold. It is necessary to carry out extensive surveys to identify both mining and extractive metallurgical sites. Metallurgical sites of various types must be excavated in detail; Bronze Age and Iron Age sites from many areas in Thailand are so far unrepresented.

Until these things are accomplished, it will not be possible to present a rational picture of the development of metallurgy in Thailand. Alongside this, improved chronological information is required for the sites that have been excavated so far, and further excavations of neolithic sites are desirable, particularly in the north-east, in order to establish whether metallurgy developed independently in Thailand or was introduced from some other area, for example from China or from Vietnam.

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